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# IMPACT OF SPATIAL ABILITY TRAINING AND ITS TRANSFER

BY

KHAIRULANUAR SAMSUDIN

B.Sc. (Hons) in Mechanical Engineering, University of Leeds, UK

M.Sc. in Adv. Manufacturing Technology, University of Portsmouth, UK

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# ABSTRACT

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This study was undertaken to examine students' perceived ability to learn basic engineering drawing, differential impacts of spatial training and training transfers. The research method used was based on the Triangulation Software Development Method, which was carried out in two parts: a Survey Research, and an Experimental Research. The survey research examined students' perceived ability in learning engineering drawing involving 355 secondary school pupils, with a mean age of 15.5 years, which was conducted through a survey. The independent variables of the survey research were spatial experience, gender and mathematical ability; the dependent variable was the perceived ability. Instruments used were Students Perception Questionnaire (SPQ) and Spatial Experience Questionnaire (SEQ). The experimental research was based on pretest-posttest design, which was carried out to examine the extent of Spatial Visualization (SV) and Mental Rotation (MR) training improvement, differential impacts attributed to gender and training method, and training transfer to engineering drawing task. Ninety-eight secondary school pupils (36 girls, 62 boys), with a mean age 15.5 years, were randomly assigned into two experimental groups and one control group. The first experimental group employed interaction-based training in a desktop virtual environment trainer, the second group used animation-based training, and the control group trained using printed materials and all groups trained for 6 weeks. Instruments used were computerized version of the Spatial Visualization (SV) and Mental Rotation (MR) tests. All data collected were analyzed using SPSS version 18. For the survey research, correlations among spatial experience, gender, and mathematics achievement with students' perceived ability to learn were significant. In general, high spatial experience respondents, boys, and high mathematics achievers tended to view the learning favorably. Several topics of engineering drawing were found to be particularly difficult namely orthographic drawing and isometric drawing. For the experimental research, analysis of the data revealed that there were substantial performance gains in SV and MR accuracy, but not in MR speed. Main effects of training in SV and MR accuracy were found; those trained using novel methods, especially in the interaction-enabled method, outperformed those trained in the conventional method.



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Interaction effects were observed where differential improvement gains in SV and MR accuracy only involved boys but not girls. Transfer of training to performance in solving engineering drawing task was observed through differential performances of groups where those with higher spatial ability solved the task much better than those with lower spatial ability after spatial training. This transfer was qualified by the multiple linear regression procedure revealing that spatial visualization was found to be significant in predicting the performance of the basic engineering drawing task. Implications of the lessons learned and recommendations for future study are also discussed.

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# CHAPTER 1

# INTRODUCTION

## 1.0 Introduction

This chapter highlights the issues surrounding the teaching and learning of engineering drawing or engineering graphics informed through previous studies involving schools and colleges in Malaysia and other countries. Several issues emerged indicating that there is a myriad of problems involving conceptual, pedagogical, and student and teacher experiential factors affecting students' performance in this subject matter. One common problem that seems to confront student ability to follow the course in engineering drawing stems from the cognitive perspective suggesting that a prerequisite ability or skill is required. This ability or skill is generically termed as spatial ability is vital in learning domains that involve problem solving that taps on visualization and manipulation of visual-spatial information. This ability has been shown as a reliable predictor of success in engineering graphics instructions, with its impact probably surpassing other factors typically studied in relation to student performance in this course.

Recognizing its importance, several interventional methods have been developed to enhance students' spatial ability where some degrees of success have been reported after training sessions. One emerging technology prominently reported in recent studies involves learning and training in virtual environments where students had gained relatively better improvement



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compared to traditional methods. However, more specific and focused training of the critical components of spatial ability, particularly in spatial visualization and mental rotation (accuracy and speed measure), is needed to ensure relevant skills are properly addressed and trained to help students acquire the required spatial skills deemed vital in engineering drawing learning.

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## 1.1 Background of the Research Study

The Ninth Malaysia Plan (NMP 2006 – 2010) implemented in year 2006 has envisioned a workforce that is technically and scientifically oriented in its quest to become industrialized nation by year 2020. About 500,000 professionals consisting of engineers, assistant engineers, architects, technologists and other specialists are urgently needed by the end of the decade (NMP 2006 – 2010, Chapter 4, p. 12). Creating this kind of workforce necessitates all relevant ministries to take pertinent measures to address these requirements and in particular the Ministry of Education (MoE) where its educational planning and implementation will have to undergo major and drastic transformation. A key objective of the plan has been the transformation of its existing industries into knowledge-based and high technology industries in order to achieve a vibrant, expanding economy. However, this highly ambitious vision would not be realizable if the nation's workforce at that point in time is lacking the relevant technical, scientific and engineering skills. Taking cognizance of the impending challenges, Malaysian government has carried out several proactive measures; and these include the current educational reform that emphasizes on upgrading the technical education at the secondary school level. Currently, there are 88 technical schools that offer various technical fields namely civil, mechanical and electrical engineering, which are located

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throughout the country, including Sabah and Sarawak. The number of this type of schools is expected to grow at a faster rate in view of the recent shift in the educational policy – a focus on technical training for future workforce.

Technology education or technological study is 'a study of technology which provides an opportunity for students to learn about the processes and knowledge related to technology that is needed to solve problems and [to] extend human potential' (ITEA , 2000, p. 242). The curriculum implemented in the technical schools consists of technical subjects that aim to prepare students with knowledge appropriate for basic engineering and technological skills. A particular subject merits attention is the *engineering drawing* subject that was initially introduced in nine technical secondary schools in 1992. The educational system for secondary schools in Malaysia had been revamped in the late 1993 that introduced *open certification system* as opposed to the previous closed certification system. The new open certification system called *Integrated Secondary School Curriculum* (*Kurikulum Bersepadu Sekolah Menengah, KBSM*) enables students at the national secondary schools (*Sekolah Menengah Kebangsaan, SMK*) to pursue compulsory or core subjects together with several elective packages. The introduction of technical subjects in these non-technical schools is a positive step taken by the MoE, having realized that technical institutional entities in Malaysia alone will not be able to prepare a highly technical workforce as needed (KPM, 1998)

Two technical subjects that are critical in preparing students to attain the crucial technical knowledge and skills are the engineering-related subjects: *engineering drawing* and *engineering technology* (KPM, 1998). The former subject was first introduced in 30 national secondary schools in 1993, and the implementation of the latter subject in 20 national secondary schools was carried in 1996 (Abu Bakar Hashim, 1995). In addition, engineering drawing is one of

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the KBSM electives in the second package of the vocational and technical grouping. Historically, engineering drawing was not a new subject offered at the technical secondary schools as it was actually a revised version from earlier courses – under different names – that essentially encompassed similar contents such as *Technical Drawing* (*Lukisan Teknik*) or *Geometrical and Building drawing* (*Lukisan Geometri dan Bangunan*) (Zainon Haroon, 1993). This subject featured prominently in these schools for students enrolled in various engineering disciplines such as civil, electrical, and mechanical. However, this subject, in its old version, had some drawbacks that were similar to other technology-oriented courses where the currency and relevancy of the technical curricula were trailing behind the fast-expanding technology. This problem is inherent in many technical disciplines, as these fields are intertwined with computing technology such as engineering, manufacturing, and design.

The new subject, namely engineering drawing is more focused and holistic as it was designed to fulfill the objectives of technical communications involving important engineering fields (i.e., civil, mechanical and electrical engineering). Having exposure to this knowledge domain is vital in developing students' awareness in a particular engineering field that interests them (KPM, 1998). The implementation of this subject in technical secondary schools was smooth as the existing conditions were conducive. However, the same was not true in the national secondary school; conditions that existed during the implementation were not conducive. For the technical schools, the implementation was merely a natural transition from old to new version of the subject matter where not much had changed in terms of teachers' proficiency, material resources and students' background. However, for the national secondary schools, the newly introduced subject had caused a host of problems from the start. Problems cropping up at the academic and administrative levels were not unexpected given the technical contents that are intellectually

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demanding and challenging, which many of this type of schools (by being non-technical secondary schools) had never experienced in handling the subject matter.

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Successful implementations of new curricula with new courses or subjects in schools will depend on many interrelated factors. Many of the issues related to the implementations of the technical courses that have been studied invariably revolve around course contents, current pedagogy, teachers' preparation, teaching and learning environments, schools' infrastructure, and students' background. In concert, some of these factors will exert an overpowering impact that determines the success of new educational programs. Poignantly, the teaching and learning process of such new courses will present new, unfamiliar challengers to pupils, teachers, instructors, and even to administrators, and educational policy makers. Thus, for this reason, the introduction of engineering drawing in technical secondary schools in general and national secondary schools in particular is of great concern to many.

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Several researchers have carried out several studies on the rate of success of this subject in relevant schools since its inception in 1993. Students' academic grades in the Malaysian Certificate of Education examination (equivalent to British O-level or American Middle Grade) were used as an indicator of success or failure for such an implementation. In this respect. the success rate for the engineering drawing introduced in year 1993 was high with 84.8% of the candidates had passed the examination; this was hardly surprising given the fact that only students in technical schools were involved. The technical students were expected to do well in view of their relatively higher academic performance. However, the following years till 1996 had witnessed a steady decline as the passing rates dropped to 60% passing rate. One of the main reasons was that students who learned this subject were not only those who

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studied in the technical schools, but pupils from the national secondary schools also pursued this subject; in general, the former were academically more proficient than the latter (Nor Fadila & Widad Othman, 1999).

Albeit the growing concerns, the year that followed saw a slight improvement, which recorded a modest 66% passing rate because several more newly established technical and science schools were involved in the implementation of this subject (LMMPT-SMA, 1998). With these new schools, the subject was then offered in three types of secondary schools: technical secondary schools, national secondary schools, and science secondary schools. The percentages of the passing rate based on the school categories were 89%, 75%, and 43% for science, technical and national secondary schools, respectively. Evidentially, students' performances were diverse based on the school categories; pupils from the science and technical secondary schools outperformed those from the national secondary school category. Similar trends of student performance is expected to persist at best or to drop drastically at worst as more national secondary schools will start offering the subject matter in the coming years.

## 1.2 Problem Statement

The current state of students' performances in engineering drawing subject has prompted several researchers to conduct several studies to identify factors that influence the process of teaching and learning of the subject matter. These researchers have investigated the challenges faced by teachers and instructors in implementing the new curriculum; more importantly, the researchers have embarked on studies to examine the effects of this implementation on the teaching and learning process, particularly focusing on

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students' performance (Nor Fadila & Widad Othman, 1999). Their findings revealed that there were several factors that have resulted in students' low performances: pupils' poor spatial ability (Ahmad Zamri, 2002;, Bektasli, 2006; Casey, Nuttall, Pezaris & Benbow,1995; Millroy & Rochford, 1985; Siemankowski & MacKnight, 1971), pupils' lack of drawing practice (Azaman, Ramlee, Shafie & Mohd Shahril, 2009; Widad Othman & Hatta Ismail, 2001), teachers' high teaching workload (Tuan Zaidi, 2002), teachers' lack of instructional experience (LMMPT-SMA,1998; Sorby & Baartmans, 1996), and gender-related learning issues favoring boys (Strong & Smith, 2002; Tartre, 1990).

Among the contributing factors, spatial ability or spatial skill of pupils is believed to be an indicator of students' performance; those with poor or inadequate spatial ability can be a detrimental to successful learning. Learning difficulties will be self-evident when poor spatial pupils start learning the core topics of engineering drawing: orthographic views, isometric views and auxiliary views. Their inability to follow the instructions of these highly demanding spatial topics will be apparent with their slow progress in developing the proper reasoning in solving spatial tasks assigned to them. To make matter even more problematic, gender factor has been shown to be a variable that could result in performance disparity, with boys in general outperforming girls. This gender disparity in engineering drawing performance is the outcome of differential levels of spatial skills that individuals might have, with boys having better spatial ability than girls do. Seen from another perspective, a host of experiential or environmental factors rather than biological factors might have shaped one's spatial ability level.

From the teaching environment perspective, many factors prevailing in the classrooms are not helping in creating conducive, supportive learning

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environments. Invariably, current teaching style is typically teacher-centered, relying too much on instructions that leave many pupils with a lack of opportunities to engage in personalized knowledge construction. Tight teaching schedule and over-emphasis on finishing the school curricula have made the problem even worse; the former results in teachers not giving enough attention to pupils' needs, and the latter makes teachers less focused on engineering drawing teaching as they have to deal with other subjects as well.

Findings from studies conducted in Malaysian schools to date have shed some lights regarding the challenges and problems faced by teachers and students in the implementation of a technology curriculum in particular engineering drawing. Studies carried out by the researchers encompass a range of issues involving cognitive and pedagogic domains, namely conceptual learning, students' experiences, teachers' experiences, and spatial ability in the teaching and learning process. Pedagogical aspects of engineering drawing instructions have been given much attention by some researchers where most agree that multiple- and flexible-instructional strategies assisted by information and multimedia technologies should be employed in the teaching process (Azaman Ishar et al., 2009; Othman & Kamaruzaman, 1995; Tuan Zaidi, 2002).

Being a relatively new subject in the school curriculum has unraveled many problems associated with the teaching and learning process. Students with different academic, school, and gender backgrounds have been observed to exhibit diverse spatial visualization ability, thus requiring appropriate instructional approaches to facilitate their learning ( Nor Fadila & Widad Othman, 1999). Consequentially, some students would encounter an array of learning problems or challenges given their shortcomings and drawbacks in this ability; thus, these problems warrant an immediate, effective remedy and intervention to mitigate the difficulties. More importantly, low spatial students

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must be given sufficient training or learning opportunities to improve their spatial skills.

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Taking cognizance of the imperative to improve students' spatial ability, new, novel methods of training have been experimented, yielding a wide spectrum of outcomes – both promising and discouraging. Current trend seems to use multimedia technologies and computer-mediated instructions as a spatial training platform. Of late, virtual reality, which is a new multimedia technology, has been shown to be a promising spatial training tool as demonstrated from recent studies by Cheong (1999), Dalgarno (2001, 2010), Kwon and Kim (2002), Mohler (2001), and Smith and Lee (2004). In spite of its apparent, euphoric appeal, it is still quite premature to conclude its educational impacts on spatial ability development training as virtual reality has still not been fully studied in many aspects of spatial skills training, as there is a diverse range of students' demography involved.

Due to the well-established research in the military applications, most educational studies that have been carried out so far are based on the immersive VR technology, which is complicated and expensive type of VR tool – beyond the reach of typical Malaysian schools. Research on desktop VR is scarce that augurs discouraging news to teachers and instructors, as this type of technology seems promising to be applied for spatial training for school children by being inexpensive, practical and capable of being used on a wider scale. Moreover, most studies that have been carried out thus far are also technology-centric (focusing on the technological dimensions), but the more important aspects related to instructional designs (supported by sound theoretical underpinnings) are unfortunately lacking.

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## 1.3 Purpose of the Study

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The discussion based on the review of the visio-spatial literature highlights a range of issues confronting the teaching and learning of engineering drawing. Demographic, psychological, and cognitive factors particularly gender, perceived ability (i.e., self-efficacy), and spatial ability exert strong impact in engineering drawing learning of secondary school students at the foundational year in Malaysia (Azaman et al., 2009; Jayasree, 2003; Othman & Kamaruzaman, 1995; Tuan Zaidi,2002). Gender seems to play an influential role where, in general, male pupils tend to view the learning of the subject matter more favorably than females. In addition, male pupils have attained relatively better examination grades than their opposite counterparts. Spatial experience of students also adds some weight in that there is a significant relation between the level of spatial activities students engaged and perceived ability or self-efficacy in learning engineering drawing. Another factor that has been determined to be influential is mathematical ability where significant correlation has been found between student's perceived ability to follow the engineering drawing instruction and this ability (Azaman et al., 2009; Nor Fadila & Widad Othman, 1999).

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Performance of students in engineering drawing courses correlates significantly with students' spatial ability, namely spatial visualization and mental rotation as observed in previous studies (Shawn & Smith, 2002; Sutton & Williams, 2006; Sutton, Williams, & McBride, 2009a). These two abilities are very important in learning domains such as engineering, architecture, and graphics courses, which rely on spatial cognition for solving technical problems. A learner should possess a highly developed visual-spatial skill or ability to learn such courses successfully. Individual differences in spatial ability may affect learning outcomes where high spatial learners have been found

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consistently to outperform low spatial learners in most studies. In addition, male students possess higher spatial skills compared to female students owing to differential backgrounds in engagement of spatial activities that favors the former. Apparently, a high level of spatial experience would suggest that there would be more opportunities to practice spatial skills, which partly contribute toward greater development in spatial ability among boys compared to girls.

Two important themes emerged from the review of the literature that mainly focuses on students' overall perception of their learning in engineering drawing and their performance in the subject matter. The first part involves factors such as gender, spatial experience, and previous mathematic achievements in relation to perceived ability to learn the subject matter (Baartmans & Sorby, 1996; Bektasli, 2006; Nor Fadila & Widad Othman, 1999; Tracy, 1987;). The second part stresses the impact of demographics, namely gender and level of spatial ability on engineering drawing performance. In addition, methods of improving spatial ability have been rigorously studied given the significant association between this ability and the performance of engineering drawing tasks. The research study carried out by the author involved two main parts, requiring two approaches in the research design; the first part was implemented through a survey research, and the second part involved an experimental research to address the prevailing problems and issues in the learning of the subject matter.

The design of the survey research was based on the explanatory paradigm in that it sought to examine the relationships among important factors involving gender, spatial experience, and previous mathematic achievements with perceived ability to learn engineering drawing. The explanatory survey investigated whether the associations of the independent variables (i.e., gender, spatial experience, and previous mathematic achievement) and dependent

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variable (i.e., perceived ability to learn) were significant or not to warrant further course of action. Given the supporting evidence from the literature that shows that learning of the subject matter is perceived differentially based on demographics, it was imperative to conduct this research to investigate the perception of student learning at the foundational year prior to pursuing the second part of the research study. In addition, information and evidence elicited from the survey should guide the design and implementation of the following part of the study, namely involving an interventional program that was to be employed in the research based on the experimental paradigm. The target group identified relevant in this study were students of Form Five level (i.e., 11th graders) that already had followed the course in the foundational year at the Form Four level (i.e., 10th grader). Their learning experiences of the subject from their previous year of study (i.e., at the 10th grade) provided useful input in the survey, which was conducted at the beginning of their second year of study (i.e., at the 11th grade).

The purpose of the second part of the research was to improve the secondary students' spatial ability, namely their spatial visualization (SV) and mental rotation (MR) through spatial activities in an interactive desktop virtual environment spatial trainer (DVEST). The spatial trainer was developed by the researcher utilizing the Virtual Reality Modeling Language (VRML): the language that enables the description, animations, and user interactions in a web setting with which a user can interact by viewing, moving, rotating, and otherwise interacting with an apparently 3D scene (Ali & Ferdig, 2002). The imperative of investigating these two cognitive abilities was informed through empirical evidence demonstrating that SV and MR are deemed vital components of spatial ability – intellectual constructs that are critical in the learning or training of technical courses that depends on spatial thinking or spatial cognition (Olkun, 2003; Sutton, Williams, & McBride, 2009b). The design of DVEST

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was informed by the principles of the constructivist theory of learning that emphasizes learners as active participants. This experimental research investigated the impact of active explorations or interactions and animations in a three-dimensional (3D) virtual environment that was guided by the instructional spatial activities that facilitated the enhancement of the SV and MR: skills deemed crucial in the learning domains such as engineering drawings or engineering graphics studies. In addition, other training methods were also examined to determine whether the novel training approach was significantly superior or not to justify its implementation in training purposes.

The creation of the virtual 3D geometrical objects in DVEST and their 3D representations on computer screen enabled the participants to interact with the virtual training objects in manners replicating the real world. The virtual environment afforded spatial training with which the participants could train in an interactive and engaging setting where they could better understand and visualize the types of complex spatial concepts, relationships, and problems that exist in technical graphics by incorporating the use of 3-D computer graphics during instructions (Mackenzie & Jansen, 1998; Mohler, 2001). In addition, the spatial activities to be practiced by the participants should provide simulation of concrete experiences, which have been proved helpful in improving students' performance in spatial visualization (National Council of Teachers of Mathematics, 1989).

Several training methods have been studied and implemented involving a diverse range of technologies and trainees' demographics to improve spatial ability as demonstrated by Keller, Wasburn-Moses, and Hart (2002); Lehmann (2000); Leopold, G'orska, and Sorby (2001); and Turos and Ervin (2000). Most of these novel instructional approaches have been developed based on the interactive media and network technologies, namely virtual reality, multimedia

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tutoring systems, and Java applets; these training tools were delivered using the Internet, which has gained prominence of late to provide training platforms for spatial training. The implementation of these interventional programs through proper instructional strategy coupled with carefully crafted exercises has the potential to help students gain basic spatial skill. This is especially vital for those enrolling in courses such as technical graphics, engineering drawing, or CAD that demand spatial reasoning to comprehend the fundamental concepts ingrained in the curriculum.

The lack of research addressing the problems associated with spatial ability among students taking engineering drawing at the secondary school level especially in Malaysia had warranted a comparative analysis of the effectiveness of spatial training methods such as DVEST with current and conventional practices. Specifically, the second part of the study, which involved an experimental research, also attempted to compare the effectiveness of spatial training through spatial exercises delivered using three instructional methods of training, namely the interaction-enabled desktop virtual environment condition, animation-enhanced desktop virtual environment condition, and conventional training (i.e., control condition) using printed materials.

The final stage of the research addressed the issue of training transfer between two domains: spatial training domain to engineering drawing task domain. Specifically, the final phase of the research sought to determine whether the spatial ability or skills acquired after spatial training could be transferred (i.e., to be applied) to a problem solving task consisting of a typical, basic engineering drawing (i.e., a multi-view orthographic drawing). Strong, positive correlation between spatial ability and performance in engineering drawing has been established in several studies where students having high spatial ability have attained higher performance in the related courses as

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compared to students of low spatial ability (Leopold et al., 2001; Sutton et al., 2009a, 2009b). Additional, there are empirical evidence highlighted in related literature cautioning gender differences and their implications from several perspectives namely biological impacts (Eals & Silverman, 1996; Geary & DeSoto, 2001; Gur et al., 2000; Hugdahl, Thomsen, & Ersland, 2006) and environmental or experiential impacts (Baenninger & Newcombe, 1995, 1989; Bussey & Bandura, 1999).

Individual differences attributed to gender and spatial experience, among other factors, that influence the learning and training in spatial ability have emerged prominently in recent studies. This focus on gender is not surprising in view of the egalitarian societies that emphasize equality in all spectrum of life – this includes education. Thus, gender factor and training method used by the participants were the thrust of the experimental research in order to determine whether there were main effects and corresponding interaction effects that might influence the outcomes of spatial training. In other words, do differential training conditions yield significant and different spatial improvements, which could be mediated by the participants' gender.

## 1.4 Research Questions

There is a nexus of issues pertaining to engineering drawing learning evidenced through a review of related literature. This served as an overture to the research to investigate the main issues and problems prevailing in the current and local context of Malaysian secondary schools that are involved with the engineering drawing instructions. This approach is highly recommended as relevant and sound research questions that emerge from relevant, related literature are seamlessly tied to the theoretical underpinnings and empirical

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soundness as espoused by Andrews (2003). Based on the main body of the discussion in the sections *Introduction* and *Literature Review*, six (6) research questions were formulated in the study as follows:

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i) Do participants' gender, spatial experience, and previous mathematics achievement affect their perceived ability to learn engineering drawing?

ii) Do participants' spatial abilities (i.e., spatial visualization and mental rotation) improve after spatial training?

iii) Do different spatial training methods result in different training outcomes?

iv) Do female and male participants achieve different improvement gains after spatial training?

The implications from the above questions would help determine the potential impact on the participants' learning of the fundamentals of engineering drawing or technical graphics such as interpreting and/or producing multi–view orthographic drawings that brings forth the following research questions as follows:

v) Is there a training transfer from training domain to engineering drawing task domain?

vi) Which component/s of the spatial ability that is/are crucial for the training transfer?

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## 1.5 Research Hypotheses

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Six (6) corresponding alternative hypotheses were formulated to address the six research questions in the study. The six alternative hypotheses are as follows:

$H_i$ Participants' gender, spatial experience, and previous mathematics achievement will have an impact on their perception in learning engineering drawing.

$H_{ii}$ There will be significant differences in spatial abilities (spatial visualization and mental rotation) of the participants before and after training.

$H_{iii}$ There will be significant differential training outcomes in spatial abilities (i.e., spatial visualization and mental rotation) based on the training methods used.

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$H_{iv}$ There will be significant differential training outcomes in spatial abilities (i.e., spatial visualization and mental rotation) based on gender.

$H_v$ There will be significant differential performances of engineering drawing task based on the training methods used.

$H_{vi}$ One sub-component of the spatial ability will significantly account for the variance of the performance of the engineering drawing task.

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## 1.6 Research Objectives

The main aim of the research was to study the amenability of spatial ability through different training conditions and its transfer to engineering drawing task. More specifically, the specific objectives of this study are thus:

i) To investigate the effects of gender, spatial experience, and mathematics achievement on pupils' perceived ability to learn engineering drawing.

ii) To investigate whether spatial ability is amendable or not to training.

iii) To investigate the differential impacts of the types of treatments on training outcomes.

iv) To investigate the differential impacts of genders on training outcomes.

v) To investigate the transfer of spatial skills acquired from spatial training to solving an engineering drawing task.

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## 1.7 Significance of the Study

The findings from the research would provide several important insights – both from the theoretical and practical perspectives – to all the stakeholders of the engineering drawing curriculum: instructional designers, subject instructors, teachers and policy makers. Learning the engineering drawing at the foundational year in Malaysian secondary schools has been a great challenge to many teachers namely because students do not have adequate and well-developed spatial ability. This ability is prerequisite to prepare students with the appropriate cognitive ability in learning the subject matter; deficient in this

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could result in students to lose motivation, self-belief and hope to follow the subject matter, which leads to poor performance.

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In the Malaysian context, the dearth of studies focusing on this issue has not been fully addressed; and the problems associated with the subject learning are expected to reach another ominous level. Impending learning and teaching challenges are expected to be more profound as existing schools that conduct the subject matter will take in more students, and other schools will start introducing this subject into their academic calendar. One of the many challenges for teachers in school instructions concerns students' low perceived ability in learning, especially among girls (Lovelle, 2007); however, only a handful research has been carried out in Malaysia to study this problem for engineering drawing instructions. Perceived ability is strongly associated with learning performance and many educational researchers and practitioners agree that low self-efficacious students tend to avoid academics and give up quickly when difficulties arise (Margolis & Mccabe, 2006).

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Thus, bringing to light students' perceptions of their engineering drawing learning to teachers would be very helpful as these teachers could foresee potential learning problems of their pupils who at risk (i.e., low self-efficacious students). In addition, determining relevant factors that influence one's perceived ability to learn this subject matter would be crucial as school administrators could institute certain policies for the course entry based on pupils' attainment of the studied factors. In other words, enrolment of students in technical courses or program could be based on candidates' spatial ability test scores.

Many researchers have debated the malleability of spatial ability to training, where previously this cognitive construct was in general perceived to

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be inherently innate; but evidence is emerging in the last few decades to suggest otherwise. Again, in Malaysia, research on students' spatial ability is almost wanting as relevant data are few and not current that would preclude a comprehensive understanding of the challenges in the implementation of the engineering drawing curriculum in Malaysian secondary schools. With more studies focusing on this issue, current information and deeper knowledge would be available to help all the stakeholders in technical curricula, especially at the secondary school level, to institute relevant plans, initiatives or reforms deemed critical and timely at this particular juncture.

One of the important factors that has been continually debated is the gender factor; and many researchers have, on many occasions, fixated on its impact on spatial ability development. Experiential and biological determinants have been theorized to cause one particular gender (i.e., boys) to develop higher spatial skills compared to the other gender (i.e., girls). The literature is replete with findings consistently showing higher performances in spatial tests by male subjects over female subjects, particularly mental rotation, which raises teaching and learning issues as many academic pursuits necessitates this intelligent construct. This gender-related problem has been dealt with full rigor and serious attention in developed nations due to the dictates of egalitarian societies, which strive for equality in education, training and work for all their citizenry irrespective of gender, race and creed. In this context, Malaysia too will experience similar challenges as it braces itself for similar educational setting. However, studies on spatial ability development based on gender are not well established; and this lack of research will be detrimental in long term, as the current trend of female representations in technical professions seems declining.

Another emerging trend is that many experimental studies have been continually carried out to seek effective and efficient methods to develop and

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improve spatial ability. Keeping abreast with the fast expanding and changing Information and Communication technology, in particular Multimedia technology, many of the training methods have utilized dazzling arrays of hardware and software, resulting in a myriad of training outcomes. Irrespective of the use of these technologies, there exist inconsistencies of training effects, which are partly attributed to the lack of theoretical-grounded frameworks used in most studies. Apparently, most studies thus far are mainly focused on hard science of training (i.e., technology-focused and instructor-centric) rather than on the soft science of training (i.e., pedagogy-focused and trainee-centric). To ensure training conditions that could optimally capitalize on the instructional contents and delivery for higher training success, the design of the training methods has to be conceptualized along the principles of a well-established, current learning theory, namely constructivism. Hence, an experimental research that focuses on spatial ability improvement using the prescribed principles would be imperative to illuminate greater insights.

The transfer of skills acquired from training setting to intended real environment is one important issue in many skills development and competency research. Premised on this context, a study to examine whether spatial ability gained from spatial training to problem solving in engineering drawing domain will provide greater understanding of the cognitive processes involved. Knowledge gained from this kind of research will help instructors to design and to develop appropriate learning and/or training materials that would tap specific thought processes rather than generic ones. Given the multi-dimensional nature of spatial ability, identifying spatial constructs that significantly correlate with engineering drawing performance would be helpful in devising a more effective training program. In essence, spatial constructs identified could be modeled and analyzed to predict performance of engineering drawing of pupils taking the subject matter. Students at risk could be easily and quickly ascertained to help

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instructors to take appropriate course of actions, which could include preventative measures rather than corrective ones.

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## 1.8 Scope and Limitations of the Study

The scope of this study was limited to investigating the impact of spatial training on two dimensions of spatial ability, namely spatial visualization and mental rotation. In addition, the sample size was not large enough to allow generalization to the larger population. Moreover, the age range of the participants was quite small as only a group of pupils from three classes of the Form Four level were used in the experimental research. Ideally, a higher range of ages encompassing all levels of secondary school pupils (i.e., from Form One to Form Five levels) would be desirable to gain in-depth knowledge pertaining to the developmental stages of spatial ability of a typical population of pupils studying in the secondary schools in Malaysia.

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In terms of school background, the school selected in this experimental research represents a typical secondary school situated in a small, urban locality; a more robust sample involving diverse school background (i.e., rural locality, small townships, and city centers) would reveal findings that are more insightful to allow generalization to actual population in the Malaysian secondary schools. Another feature that would be more practical, in view of a multi-racial country like Malaysia, is to include ethnic factor in the analysis. Findings from this analysis would provide useful information to policy makers to improve existing situation (if such scenario exists).

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## 1.9 Operational Definitions

For the purpose of this research, the following definitions help to explain the terminologies used throughout the main text of the thesis.

*Animation:*

The display of picture frames in rapid succession that creates the impression of motions or movements to the computer users.

*Client interface:*

A computer interface that has an array of clickable buttons to allow users to active or to manipulate the virtual objects displayed on the computer screen.

*Interaction:*

Actions performed by users through the navigational buttons that effectively creates impression of changing locations and orientations of virtual objects displayed on the computer screen.

*Perceived ability:*

Self-belief of pupils to perform tasks such as to learn a particular topic by investing efforts that commensurate with their levels of belief.

*Spatial loading:*

Conceptualized construct that provides a measure of the mental efforts used in manipulating spatial, mental pictures in the mind.

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## 1.10 Summary

The review of the related literature that discusses many findings from previous studies have highlighted issues and problems confronting the teaching and learning of engineering drawing or technical graphics at the secondary school level. A majority of the problems faced by the students are diverse involving cognitive and pedagogical aspects, but a recurring theme seems to revolve around one important cognitive dimension namely spatial ability. Students' performances in engineering drawing course are significantly correlated to their levels of spatial ability where there is a high risk of failure or poor grade for those with relatively low spatial skills. Emphasis to train students in this ability, namely spatial visualization and mental rotation is needed to equip them with adequate ability prior to learning the subject matter. Current focus is on using new technology, namely desktop virtual reality technology to develop a training platform that is efficacious and effective for spatial training. This new technology affords educational features such as exploration, interactions, and animations that can help improve the training process where learners can engage in active learning. Six research questions were formulated to set the agenda of the research study that would be addressed by six corresponding research hypotheses through a two-stage research: a survey research and an experimental research.

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# CHAPTER 2

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# LITERATURE REVIEW

## 2.0 Introduction

This chapter discusses the literature pertaining to the fundamentals of engineering drawing, spatial ability, current theories of learning, and their inter-relationships. Learning the basics of an engineering drawing essentially involves the production and interpretation of orthographic and isometric views. The process of learning the basic engineering drawing hinges on learners' ability to perceive, visualize and manipulate the images of a three dimensional object in the mind. Interpreting and producing an engineering drawing will be compromised if one's spatial ability is not adequately developed. Spatial ability is not a single cognitive construct but consists of several dimensions namely spatial visualization, mental rotation and spatial perception.

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The development of spatial ability is influenced both by the biological (i.e., nature) and environmental/experiential (i.e., nurture) factors. The former partly contributes to the gender differences in the early cognitive development of individuals and the latter suggests that spatial ability development is contingent on spatial experiences engaged throughout one's life especially in formal education. Several methods have been developed to improve this ability with some degree of success. In this study, an interactive desktop virtual environment spatial trainer was developed based on the constructivist perspective of learning that can help learners to improve their spatial ability



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using spatial exercises that are enhanced with interaction and animation of the virtual learning objects in the three-dimensional computer generated world.

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## 2.1 Engineering Drawing: The Subject Matter

Drawing is a language equivalent to the spoken and written language in the origination and communication of ideas. It is a language critical to the perceptual development of students. Drawing trains the eye and informs the senses, developing keen sight and enhancing perception. Equipped with this knowledge, differences and similarities are observed, meaningful patterns are recognized and metaphorical language is developed. "Drawings can be considered as a cognitive tool that helps students to visualize the structure of an idea, to process the structure line by line, and to provide a fluid means of confirmation using simple tool such as paper and pencil (Giesecke et al., 2002). More specifically, engineering drawings or technical graphics is a means of communicating technical ideas using graphical images (Bertoline & Wiebe, 2002; Wiebe, 1998)." Exercising and practicing graphical techniques could enhance visual understanding and further broaden students' visual library of forms, details, and potential applications (Anderson, 1999). The imperative to improve the curriculum of this knowledge domain is gaining prominence as it is synergistically linked with creative problem-solving and formation of concepts. Developing the ability to understand and apply this visual language can only be achieved through well designed drawing practices that are guided by current teaching and learning models applicable to schools, colleges, and institutions of higher learning.

The primary objective of engineering drawing instructions is to train students to everyday drafting practice so that they can read and produce proper engineering drawings. More importantly, through training, pupils can concisely



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and clearly communicate all the needed specifications to transform ideas into physical forms (Giesecke et al., 2002). The development of the skills to enable design ideas to be communicated by graphical techniques is formally addressed through instructions as early as in the middle secondary level. Initially, time is spent to assist students to visualize 3D objects represented by 2D drawings; concurrently, standard drawing room practices are introduced at the same time. "Approximately half the time is spent on engineering drawing proper: problem solving that involves a technique of representing 3D forms into 2D space either on paper or on a computer screen based on a projection system. Baartmans and Sorby (1996) state that '…[the] standard drawing layout typically includes the top, front, and right-side views of the object as well as an isometric or corner view of the object'." Sectional views may also be needed to show the interior details of a complex object.

In essence, engineering drawing principles are derived from the work of Gaspard Monge (1746-1818) that formalized the method of representing shapes by projecting views of an object onto two mutually perpendicular planes: a vertical plane on which elevations were drawn, and a horizontal plane on which plans were drawn (Booker, 1979). The Mongian principle is still applied today where 3D forms are represented in two dimensions by mapping points on the object into multiple mutually perpendicular planes of projection using parallel projector that are normal to the planes of projection. From the projection of points, the projection of *edges* of the object is derived, and from the edges the *surfaces* that bound the object is determined. Projection in 2D space is obtained by 'unfolding' the multiple perpendicular planes of projection into a single plane that is termed as *orthographic projection.* Another method of projection used in engineering drawing is where the projection into a single plane that in general not aligned with any of the main faces of the object is known as a *pictorial projection* that includes *oblique and perspective projections.* An important subset of projection system commonly used in engineering drawing is the

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*isometric projection*, a type of an *axonometric projection* under the oblique projection category based on a reclassification of British Standard 1192 (Willats, 1997).

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As a means of graphical communication, engineering drawing comprises some technical rules or drawing conventions. Technical rules provide standardization for the production of engineering drawings such as the specifications contained in British Standard Institution's BS308 (1990) or American National Standards Institute Y14 series. Students are normally taught the basic conventions such as the line-styles and line weights, sectional views, first- and third-angle projections, pictorial projection, dimensioning and tolerances. Strict adherence to one particular standard is very important to ensure engineering drawings are not only created with the correct syntax but most importantly it is correctly interpreted for their production. Failure to observe this rule can result in misinterpretations of drawing information that will cause grave consequences in any product design and development at a later stage.

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Students can develop the ability to use pictorial and orthographic drawings as a creative tool. The engineering drawing subject has been designed primarily around the needs of technical students, though many art students have also pursued the subject. The basic philosophy is to introduce student to as many fundamental concepts as reasonably one could muster in a year or so. Neatness and skill development are encouraged but are considered of secondary importance in the course. The subject content revolves around the theory and practice of orthographic projection and the interpretation of drawings produced by the techniques. Students who could successfully study the subject would be able to read and to produce working drawings, and will be able to express "themselves" more effectively through the techniques.



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The basis of engineering drawing is *line drawing* that is a representation of a 3D object because of the abstraction of geometric properties of the object. It should be noted that human beings could recognize something only through some kind of abstraction without which there will be no recognition (Wiebe, 1998). Thus, engineering drawings serve as a vital substitute for real 3D objects, providing a means of recognition closely related to the nature of the perceptual systems of human beings because humans detect visual information through the eyes which are 2D detectors.

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## 2.2 The Relationship between Spatial Ability and Engineering Drawing

Engineering drawing as described by Davies (1973) is as a language, which expresses itself through the medium of lines instead of words. This language has been considered far superior to any other system of communication and that information, particularly technical information, transmitted in pictorial form is universally understood. However, most geometrical data and information in engineering drawings are represented in a 2D plane surface requiring a certain level of spatial ability necessary to visualize a 3D object drawn. " Davies (1973) explains that learning engineering drawing would involve perception of pictorial information that can be considered from two aspects: the spatial perception of a draughtsman to produce suitable drawings of an object from a given specification, and" that required by the engineer to manufacture the component from the drawings.

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Different forms of perception occur between these two processes. Representing a 3D object on a 2D plane surface is contemplated by the draftsman while the engineer must create a 3D object by working from the 2D representation of the object. "The second perceptual processing is more difficult because the integration of a number of different views into a single spatial image



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relies on the correct reading of the views and therefore requires more neural attention (Yue, 2007; Roorda, 1994; Lord, 1985). Thus, the ability to see the relationship between the 2D and 3D characteristics of an object plays the central role in engineering drawing instructions (Williams, 2004)."

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Understanding drawings means visualizing correctly the geometrical form and the spatial layout of the object portrayed (Olkun, 2003; Roorda, 1994). In essence, an engineering drawing comprises many basic geometrical entities such as lines circles, triangles, plane surfaces and solid figures. "Spatial ability is required in learning engineering drawing as the manipulation of these geometrical entities and the transformation between them are to be performed by the learner. Drawing perspectives or imagining the real object from orthographic views also involves the mental integration (Olkun, 2003). More critical, Spencer (1965) emphasizes that extraction of information from drawings is an essential part of the process of visualizing 3D objects." A 3D model of an object can be held in the imagination of a viewer if correct visual information is successfully extracted from the drawing, which implies a meaning is attached to the information. "An incomplete model of the object will be visualized if only a portion of the part of the information is given meaning by the viewer. In the worst case scenario, the viewer will have no understanding at all about the 3D nature of the object represented by the drawing if no meaning is attached to any of the information."

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Studies showing the link between spatial visualization ability and engineering drawing and design are well established such as the "research carried out by Ferguson (1992, 1997), Olkun (2003), Shawn and Smith (2002), and Sutton and Williams (2006). In general, significant correlations between spatial visualization skills and success in engineering and mathematics have been found to exist that are even higher than verbal or intelligence test scores (McGee, 1979). Sorby and Baartmans (1996) argue the importance of spatial



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visualization to be an integral part of the successful learning of technical graphics and engineering as a whole. This argument is further emphasized by Ahmed, Mahdjoubi, Feng, and Leach's (2004) study that engineering learning involving CAD, technical graphics or engineering drawing hinges on students' initial ability of spatial visualization to develop an understanding of building concepts and components where a lack of this ability may form a learning barrier."

Similarly, the importance of spatial reasoning in engineering drawing learning is highlighted by a study emphasizing course topics that encourage the development of spatial visualization skills ( Miller, 1996). "Bertoline, Burton and Wiley (1992) stress that visualization ability is central to design, and that imagery provides the bridge between design ideas and their representation in sketching and drawing. Utilizing visual images as an essential part of the design process was not only reported by practicing engineers, but many teachers of engineering graphics state that visualization forms an integral part of the courses they teach (Taylor, 1980)." Thus, there will some risks if students taking such courses do not possess adequate spatial skills, which can potentially predispose them to learning difficulty particularly when the contents of learning are cognitively challenging. If this problem prolonged, this particular group of learners would be vulnerable to academic threats such as anxiety or stress discouraging them to concentrate or to remain focused throughout the learning process.

The findings of these studies strongly suggest that learning of engineering drawing entails learners to posses an adequate level of spatial ability for the successful creation, reading and interpretation of technical drawings. "These spatial skills enhance learners' cognitive capacity to extract implicit visual-spatial information in two-dimensional form contained in an engineering drawing for the construction of 3D mental models of the object drawn." Thus,

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effort to improve spatial ability of students taking engineering drawing course in particular and other engineering- and" technology-related courses in general is therefore not only desirable but crucial.

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### 2.2.1 Definitions and Dimensions of Spatial Ability

The review of studies in the preceding section implies that spatial ability is a vital cognitive ability for the success in engineering, science, arts, and mathematics education. Its implication in learning is even more profound in domains of knowledge that are spatial in nature such as engineering drawing course. The exact meaning of spatial ability, effective methods to develop this ability and factors that affect its development are still under investigations and debates. Various definitions have been used to describe the precise meaning of spatial ability in the visuo-spatial literature. The term spatial ability identifies what has also been labeled as spatial cognition, spatial reasoning, spatial intelligence, and spatial sense. "According to Smith (1983), these diverse definitions make it difficult be precise about its meaning, which further adds more intricacies and sophistication to its discussion."

The process of developing this ability and the implementation of training methods for "spatial improvement have been a significant concern of educators, psychologists and instructors (Pellegrino, Alderton, & Shute, 1983; Smith, 1964; Yilmaz, 2009)." "One consensus derived from the literature is that low spatial students would likely face some learning difficulties in colleges and schools as early as they first learn the subject matter (Bertoline, 1992). Renowned psychologist Gardner (1983) in his influential book titled "Frames of mind" posits spatial intelligence as one of the seven distinct types of intelligence where his account of spatial intelligence touches upon the ability to convey a sense of the "whole" of a subject, a "gestalt" organization, different from a



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logical-mathematical kind of organization." "The ability to impart a non-logical wholeness to form may be a function of the spatial intelligence." He asserts that spatial intelligence emerged as an amalgam of abilities and that practice in one of these areas stimulates development of skills in related areas.According to the National Council of Teachers of Mathematics (1989), spatial sense is described as an intuitive feel for one's surroundings and objects in them. To develop this sense, students must have many experiences that focus on geometric relationships; the direction, orientation, and perspectives of object in space; the relative shapes and sizes of figures and objects; and how a change in shape relates to a change in size. "Linn and Peterson (1985) defined spatial reasoning as '...skills in representing, transforming, generating and recalling symbolic, nonlinguistic information'. On the other hand, Clements and Battista (1992) argue that spatial reasoning represents cognitive processes by which mental representations of spatial objects, relationships and transformation are constructed and manipulated. Spatial ability is defined as spatial cognition dealing with spatial features, properties, categories and relations in terms of which we perceive, store and remember objects, persons, events, and on the basis of which we construct explicit, lexical, geometric, cartographic, and artistic representations (Olson & Bialystok, 1983)." Similarly, Bertoline (1998) defined spatial cognition as the mental process used to perceive, store, recall, create, edit, and communicate spatial images.

The ability to think quickly and to construct complex mental models is a sign of spatial intelligence representing an important prerequisite to engineering graphics learning. "A pioneering study by Thurstone and Thurstone (1949) concludes that spatial ability as a non-unitary cognitive construct that can be categorized into three skills: recognizing an object from different angles, imagining displacement or movement of internal parts of a spatial configuration, and determining spatial relationships with respect to one's own body. On the other hand," "Lohman (1979) characterizes spatial thinking in terms of three


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spatial categories; spatial relation – the mental rotation of a visual stimulus, spatial orientation – how a stimulus appears from various perspectives, and spatial visualization" – the internal reproduction of spatial information such as from the mental unfolding of geometric shapes.

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"The attempts to classify spatial ability into several components have been controversial and compliance to a single, standard categorization has not been reached to date indicating that full understanding of this ability is still evolving through more studies. "Nonetheless, Linn and Peterson (1985) had carried out a meta-analysis of studies performed between 1974 and 1982 and made a classification of spatial ability based on spatial tests into three categories: spatial perception, spatial visualization and mental rotation." "This categorization clearly parallels Thurstone's classification of spatial ability." Spatial perception deals with a person's ability to determine spatial relations despite distracting spatial information. The ability to manipulate complex spatial information through several and sequential stages in order to derive a correct solution is considered as an individual's spatial visualization and mental rotation is the ability to quickly and accurately rotate two- or three-dimensional objects in one's mind. "In addition, Kolb and Whishaw (1990) split mental rotation dimension into two categories namely visualization and orientation. Visualization is the ability to manipulate or rotate two- or three-dimensional pictorially presented stimulus objects." "This visualization aspect of mental rotation is the same as Linn and Petersen's (1985) overall definition of mental rotation."

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Spatial orientation is the ability to remain unconfused by the changing orientation in which spatial configuration may be presented (Kolb & Whishaw, 1990). "In a similar classification, Maier (1994) conceptualizes spatial ability as a multi-facet ability made up of five components – spatial perception, spatial visualization, mental rotations, spatial relations and spatial orientation." "Spatial



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relations according to Bertoline [25] is an understanding of the relationship between static or dynamic objects in space and whereas McGee (1998) states that spatial orientation is the comprehension of the arrangement of elements within a visual stimulus pattern and the aptitude to remain unconfused by the changing orientation in which a spatial configuration may be presented." "He also defined spatial visualization as the '... ability to mentally manipulate, rotate, twist or invert a pictorially presented stimuli'."

Of all the above dimensions discussed, two spatial factors consistently emerge as critical and prominent components of spatial ability: spatial visualization and spatial orientation (Strong & Smith, 2002). "Both factors involve some kind of mental manipulation of visual images." " Findings from Kovac's (1986) and Shepard and Cooper's (1982) studies have led to a general consensus that spatial ability is a mental manipulation of objects and their parts in 2D and 3D space where the combination of spatial visualization and spatial orientation forms the basis of spatial ability." Amidst the different and overlapping spatial factors above, spatial problem solving seems to represent two correlated dimensions of performance that are speed-power and complexity (Pellegrino et al., 1983). Various spatial tests have been developed to measure students' performance based on these two dimensions (Yilmaz, 2009). In general, spatial relations tests require subjects to complete spatial tasks in certain time where speed is vital; however, spatial visualization tests emphasize more on power (i.e., accuracy) over speed (i.e., reaction times ) (Olkun, 2003; Yilmaz, 2009).

Spatial tests have been developed to measure subjects' performance in spatial tasks that demand these spatial components of spatial ability in problem solving. Each test comprises a single trial where subjects will be tested on spatial task without any prior study or practice. Rod-and-Frame test (RFT) and Water Level Test were originally developed by Witkin and Ash (1948), and

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Piaget and Inhelder (1956) respectively are two tests designed to evaluate the spatial perception category. The spatial visualization category can be tested from several tests from standardized test batteries such as Paper Folding by Ekstrom, French, and Harman (1976), Paper Form Board by Likert & Quasha (1941), Identical Blocks Test by Starfford (1961), and Embedded Figures Test by Witkin (1950). In addition, the Card Rotation Test by Ekstrom et al., (1976) and Primary Mental Abilities Test:Spatial Relations by Thurstone (1958) are examples of the commonly used instruments to test the mental rotation component of spatial ability. These tests represent 'pencil-and-paper' classical psychometric instruments that were widely used in cognitive- psychological testing a few decades ago; however, novel, computer-based spatial tests have been developed that facilitate quick and accurate data collection and analysis.

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### 2.2.2 Factors Influencing Spatial Ability Acquisition

Several cognitive-psychological studies have identified various factors that may impact on individuals' spatial ability. "Demographic factors namely age, gender, and spatial experience have been identified to exert significant influence in the development of one's spatial ability ( Miller, 1996; Yilmaz, 2009)". In addition, socio-cultural and cognitive attributes (i.e., aptitudes) have been studied revealing a range of opinions and thoughts deduced from empirical evidence with regard to the acquisition and improvement of spatial ability. In addition, biological influences on spatial ability development have been and are continually being studied by psychologists and cognitive scientists to gain greater insights of the brain's neural functions that shape one's spatial intelligence.

In general, individuals who have greater experience in non-academics activities that are visuo-spatial in nature will be superior in terms of spatial



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ability than those with lesser experience. These activities may include model building, sketching, and assembly of parts during elementary and middle schools years. Deno (1995) investigated the effects of previous design and mechanical experiences on beginning engineering students have on spatial visualization ability. Significant positive correlation was found between subjects having higher involvement in these spatial activities with spatial visualization tests. Children who had played with model building kits such as LEGOS in preschools and a free-form play context seemed to exhibit high spatial ability. Serbin and Connor (1979) found a strong positive correlation between visuo-spatial performance and play with toys such as blocks, Lincoln Logs, Tinker Toys, Lego blocks, and Erector sets." The toys these children played provide them with concrete experiences in the manipulation of objects, patterns, construction, and movement through space.

"Tracy (1987) observed that playing educational toys engrosses children in spatial learning as the toys must be manipulated so that they can 'work'. Children's early experiences in activities involving manipulative and paper-cutting, and folding and unfolding activities proved to be a contributing factor in improving children's spatial ability." "Ben-Chain, Lappan, and Houang (1988) caution that deficient in manipulative experience may result in some children having difficulties in 'seeing' hidden parts." In addition, Piaget and Inhelder, (1948) remark that children that are familiar with paper folding and unfolding are two or three years advanced in spatial skills than children who lacked this experience.

Many studies have shown that in general, male participants have consistently outperformed their female counterparts. "The largest gender difference can be found in tests of mental rotation and spatial visualization to a certain degree (Lehmann, 2000; Lin & Hyde, 1989; Quaiser-Pohl & Lehmann, 2002; Richardson, 1994; Robert & Bell, 2000a, 2000b; Voyer, Nolan, & Voyer,

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2000; Voyer, Voyer & Bryden, 1995)." Finding from an earlier study on spatial ability differences carried out by Eisenberg and McGinty (1977) was quite compelling when they concluded that women might be two or three times more likely to lag behind men in three-dimensional spatial skills. "One major reason for the gender gap is that females had less experience with activities crucial for the development of spatial skills (Quaiser-Pohl & Lehmann, 2002; Williams, Sutton, & Allen, 2008). Performance of mental rotation tasks entails relatively fast response time and not entirely on complexity that generally concurs with a postulated female preference to work more slowly, meticulously and would rather omit than guess on spatial tasks owing to the lack of experience and poor self-confidence (Goldstein, Haldane, & Mitchell, 1990)." "Gender differences in spatial ability may not only introduce educational ramifications, but on a larger context, they can combine with other psychological and social factors that determine the career paths of college graduates (Burin, Delgado, & Prieto, 2000; Hegarty & Waller, 2005)."

Though "there is a general trend of gender differences favoring males in the literature, there are some studies such as discussed by Halpern and Collaer (2005) that revealed females' performance in some spatial tests are comparable to males." Some visuo-spatial performance tasks include a measure of speed and men's superior performance only reflects their ability to perform the task faster than women, not more accurately. Most researchers agree that women perform equally well as men in spatial visualization tasks except in tasks involving spatial perception and spatial orientation or mental rotation abilities. Regardless whether the gender differences between the genders are significant or no, efforts to improve spatial ability grows more and more imperative especially for students pursuing engineering or technical fields through appropriate instructions or interventional treatment (Sorby & Baartmans, 1996).

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"The development of spatial ability peaks at the adolescent age and will gradually decline in the late twenties in the general populations due to aging effect even among individuals who are using these abilities in their profession (Salthouse, Babcock, Skovronek, Debora, Mitchel & Palmon, 1990)." The optimal age for acquiring spatial ability is between eleven and twelve years old as suggested by Ben-Chaim and his colleagues (1988), which underscores the importance of spatial training for pupils particularly the middle graders. Piaget and Inhelder (1967) theorized the development of spatial cognition comprising four stages based on age. The first is the *sensomotor* commencing from birth to the age of approximately two where a child exhibits a purely egocentric view of the world and knowledge is gained through perceptual sensation. The second is the *pre-operational* that develops from the age of two to seven where the child continues to adopt the egocentric view and knowledge is gained through by touch. The third is the *concrete operational* that builds up from the age of seven to 12 where the child develops spatial thoughts independent of images but still requires the actual presence of the object being manipulated. The fourth is the *formal operational* taking effect from the age of 13 to adulthood where the child is capable of exploring mental manipulation involving infinite spatial possibilities and complex mathematical concepts. The developmental stages posited suggests that an individual can be trained in order to develop spatial ability formally in schools from the seventh grade onwards, concurring with the view espoused by Ben-Chaim and his colleagues. Missing this opportunity will deprive the students to gain sufficient spatial skills most needed in learning engineering drawing.

Cultural influence does exist where differences in spatial ability vary in magnitude involving many different countries. Early study by Mitchelmore (1980) revealed that British students performed slightly better in visuo-spatial and drawing ability than pupils of similar age in North America suggesting that even in developed nations there are potential differences in spatial skills. The


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difference was partly attributed to different classroom practice where more instructional materials such as manipulatives were being used more extensively in the British classrooms. "Porter and Van Der Merwe's (2001) study showed that 80% of African students failed their course in comparison to their White Afrikaans peers that raised concerns among instructors. Inferior learning environments experienced by the former were a likely source of poor performance of the subject matter." A study by Flaherty (2005) that compared mental rotation ability in three cultures – Ireland, Japan and Ecuador – found that subjects from the first two countries scored higher than their counterparts in the latter country. Again this demonstrates the influence of culture and experience with spatial activities in the performance on spatial ability.

In addition, some studies have revealed significant relationship between spatial visualization ability and aptitude or general intelligence. "Kyllonen, Lohman, and Snow (1984) found that aptitude influences the choice of strategy, which according to Schultz (1991) can in turn affect spatial ability tests performance. Evidently, the process of imparting spatial ability to students is governed by several factors as discussed. Spatial ability is a multi-facet ability such that an attempt to train this ability may have to take into account a host of factors that are interrelated. The development of this ability is influenced by many factors such as academic background, prior experiences, ages, cultural background and gender. Educators, instructional designers and instructors should be fully aware of the potential impact that they exert in the teaching and learning process. Student diversity can introduce interaction effects in spatial training where intended training outcomes could be mediated by many variables making interventional, remedial programs challenging." In spite of these challenges, training to improve this ability must be pursued given its significant relation with the instructions of engineering drawing courses (1997).

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### 2.2.3 Improving Spatial Ability

Spatial ability is a prerequisite in learning engineering drawing involving the creation and interpretation of technical documents. This ability helps students to process visuo-spatial information through the perception of graphical symbols and the subsequent manipulation of mental imagery in their minds and to externalize the interpretation of their understanding through a proper drawing format. The ability to read, create and understand engineering drawings is a key to the success in learning engineering drawing or engineering graphics. Spatial visualization and mental rotation are the components of this ability most needed to understand orthographic and isometric views in an engineering drawing. However, experiences from schools showed that most students taking engineering, architectural and technology-related courses in the beginning of their study were often frustrated by their inability to visualize objects presented in the engineering drawings. Consequently, improving spatial ability and determining the effective methods for training are becoming more and more imperative in addressing the issues in the engineering drawing instructions.

The "amenable versus inheritable attributes (i.e., nurture vs. nature) of spatial ability has fascinated many researchers. Lord (1985) utilized instructional intervention using 'plane through solid' imposing students to visualize the cross-sectional slice of a three-dimensional shape and predict the two-dimensional shape of the cut surface." Students that received the treatment performed significantly better in post-tests of spatial tasks compared to the control group suggesting that spatial ability is amenable to training. "Similarly, Brinkmann (1963) had performed a series of post-tests of students having trained through 'programmed-instruction' stressing on concrete object manipulation in spatial visualization activities showed significant scores than a control group on the same tests. Findings as reported by Keller et al. (2002), Kwon and Kim (2002), Suppiah (2005), and Turos and Ervin (2000) provide further evidence that



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spatial ability may be more closely related to experience rather than heredity. It has been shown that experiences with visualization tasks can significantly improve individual's ability and confidence in that field especially for those who begin study with inferior ability (His et al., 1997). A distinction has been proposed to differentiate between spatial ability and spatial skill. Spatial ability is innate that we are born with." On the other hand, "spatial skill is defined as the spatial ability acquired through training (Sueoka & Yokosawa, 2001)." This implies that spatial ability can be trained through training using proper and adequate instructional tools and materials (Bishop, 1989).

"Pioneering work by Davies (1973) had observed activities that could help pupils to develop this skill through modeling engineering components with modeling clay, construction of line models with plastic straws, work with 3D stereoscopic spectacles, work with mirror, and work with transparent Perspex models. These activities provide students with additional concrete experience on which they could base their perception of objects. Activities that provide hands-on experience to enhance children's spatial ability have long been posited by earlier psychologists and scientists. "Piaget and Inhelder (1948) theorized that the combination of hands-on touching and integration of different viewpoints is instrumental in children's development of spatial ability and mental models of spatial objects." Their recommended approach can be efficiently implemented in today's realm of computing as demonstrated by some studies that capitalize on the interactive video games and computer applications (Eisenberg, 1999; Gagnon, 1985; Keller et al., 2002; Lieberman, 2006).

An innovative research by Eisenberg (1999) studied the effect of the integration of manipulatives and computer program for four years across different age groups and modes of representations. The overall result of her research indicates that children's spatial visualization ability improved significantly based on their performances in several standardized tests of

visualization. The knowledge gained from her research suggests that computer environment can be a powerful tool to promote spatial thinking in combination with real-world activities. "Recent studies showed promising results of spatial training in computerized environments which are either comparable or superior to traditional approaches based on pencil-and-paper activities and physical manipulatives. "A project called *Illumination* by Keller et al. (2002) unveiled promising results of spatial ability improvement based on web-based learning environment using applets. These applets provided features to allow students to create and reason about many isometric drawings using cubes, faces or edges." Analysis on students' work indicated that these applet-based instructional materials had improved their spatial ability as evidenced by their ability to create isometric drawings, connect isometric drawings with other 2D representations of 3D objects, and translate among these representations.

Discussed above are some of the learning approaches or instructional strategies developed in the last few decades to assist students in acquiring spatial skill. Numerous methods have been employed and studied that include traditional paper and pencil, real models, 2D and 3D computer-aided designs, 3D animations and computer games. All these methods have been used for spatial training that produced diverse, mixed outcomes. Of late, the use of computerized learning environments that mostly employ multimedia technology has been making great strides. Most computer programs developed for this purpose allow not only the creation of 3D representation of objects, but they also afford interactions with the models which is vital towards students' understanding of the concepts of spatial objects, its properties, and relations that runs parallel with Piagetian theory." One of the most promising multimedia technologies for spatial learning is virtual reality (VR) or virtual environment (VE) that according to McLellan (1998)] allows people to expand their perception of the real world in ways that were previously impossible. VR can be applied in a range of training and learning contexts because '...it covers a wide



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spectrum of training and learning areas from teaching simple tasks to the acquisition of complex skills such as abstract reasoning, visualization and management of complex information spaces (Salzman, Dede, Loftin, & Chen, 1999). "Training spatial skill is one of the many fields VR has been instrumental in developing learner's cognitive, affective, and" motor skills.

Educational benefits offered by virtual reality have been highlighted by many researchers particularly in areas of spatial visualization improvement (Pantelidis, 2000). Merickel's (1992) empirical study on children's perceptions in the virtual world supports the claims that VR can aid in enhancing spatial skills. Children trained to solve spatially related problems, both in two and three dimensions exhibited improvement in their visualization and mental manipulation abilities. "Kwon and Kim (2002) demonstrated the training capability of desktop VR to improve spatial skill of a group of female students from two high schools in South Korea." " Two web-based instructional programs were built, one using virtual environment encoded in VRML and the other just containing text and static images. Better performance in particular for tasks involving three-dimensional rotation skills was observed for those trained in the web-based virtual environment compared to the other group. Training involving dynamics behaviors of and interactions with the virtual world resulted in higher spatial comprehension of objects in 3D space." Their overall finding reinforces the claims for wider use of multimedia technology particularly the desktop VR in spatial training that provides low-cost but effective solutions.

The use of VR in learning and training entails a well designed approach in view of the diverse technological issues for educational applications. "Osberg (1993) argues that many technological, theoretical, economical and cultural challenges still have to be faced for further integration of VR into educational and training contexts." VR is a mature technology in military applications and research fields, but it is quite recent in educational field requiring more research


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to study its usefulness. Nonetheless, educational VR is not a farfetched notion as new research initiatives are emerging that demonstrate its many attributes that can be harnessed to improve cognition. "Mantovani (2001, p.209) strongly believes that VR serves as a tool for developing instructions along constructivist lines providing environments in which learners can actively pursue their knowledge needs." The attractive aspect inherent in VR is that it is an enabling tool or technology capable of applying educational theories in the "real world". VR supporters have a strong passion for constructivist learning because of its provision for a philosophical foundation for their activities."

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## 2.3 The process of learning

"It is vital to understand what really takes place when students are engaged in learning or training activities which effects a change in their cognitive and/or affective levels. This entails a review of the current learning theories, and their instructional applications in learning or training. Baruque and Milo (2004) contend that learning theories play an important role in the design and development of learning or training objects, and according to Suaalii and Bhattacharya (2007) the environments using such objects can facilitate meaningful learning or training. "Some definitions of learning lean towards the notion of observing behavioral changes. Kimble (1961) argues that learning results in '… [a] relatively permanent change in behavioral potentiality that occurs as a result of reinforced practice'." This indicates that any behavioral change constitutes learning and the occurrence of learning is attributed to the specific change in behavior brought about by experience.

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However, some psychologists oppose the idea of approaching learning as an outcome (i.e., the product of some process). They argue that not all changes



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in behavior resulting from experience involve learning. It would seem fair to expect that if learning has taken place, experience should have been used in some way. A change in behavior may result from conditioning, but the change may not involve drawing upon experience to generate new knowledge. There is a concern with what happens when learning takes place. Learning could be thought of as a process by which behavior changes due to experience. Gaining knowledge or ability through the use of experience is the focus for learners. Through the two approaches in understanding learning as an end product or as a process has resulted in several learning theories and perspectives, namely behaviorist, cognitivist, and constructivist."

The study of overt observable, measurable behaviors is the pivotal point of the theory of behaviorism based on treatises of Pavlov, Watson, Thorndike and Skinner (Good & Brophy, 1990). Behaviorists contend that learning consists of the formation of links between specific stimuli and responses through the application of rewards. The mind is viewed as a 'black box' in the sense that response to stimulus can be observed quantitatively, totally ignoring the possibility of thought processes occurring in the mind. The objective of behavioral learning is summed up in 'specified, quantifiable, terminal behavior' (Saettler, 1990). This entails breaking down a learning task through analysis into specific, measurable tasks. The learning success may be measured by tests developed to measure each objective.

Cognitivism emerges to explain certain social behaviors and internal mental processes that were not addressed by behaviorist perspective. Knowledge is assumed to exist separate from the individual that can be transferred into the learner and learning involves associations established through contiguity and repetition. Cognitivists also acknowledge the importance of reinforcement, although they stress its role in providing feedback about the correctness of responses. However, cognitivists put the mind back into the learning equation.

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While accepting such behavioristic concepts, cognitive theorists view learning as '...involving the acquisition or reorganization of the cognitive structures through which humans process and store information' (Good & Brophy, 1990).

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The main goal of instruction based on cognitivist learning focuses on the communication or transfer of knowledge to learners in the most efficient, effective manner possible. The teacher assists learners in developing meaning by providing activities that they can work through. The teacher provides a structure and/or helps learners to create a structure to which is added new learning. Learners are provided with opportunities to examine the same activity under different conditions or situations. New information is presented during the use of a well known activity to facilitate the creation of meaningful links between old and new information. Students are provided with positive feedback to guide their future thinking and symbolic or model creation.

Constructivism fundamentally posits that learners actively construct their own knowledge and meaning from their experiences. However, constructivists argue strongly that knowledge constructions do not necessarily bear any correspondence to external reality. That is, they do not have to reflect the world as it really is to be useful and viable. Learning results in changes in the whole person in values and perspectives, not merely changes in behavior and cognitive processes. Some of the established and influential constructivist theorists are Kant, Piaget, Vygotsky, and Dewey. The constructivist view of learning can be explained in terms of three broad principles. As individual constructs his or her own knowledge, therefore, no two people's knowledge can be the same.

This principle was originally articulated by Kant and was later adopted by Dewey (cited in Von Glaserfeld, 1984). The second principle, normally attributed to Piaget (cited in Mclnerney & Mclnerney, 1994) informs that learning occurs when, during active exploration of the knowledge domain, learners uncovers a deficiency in their knowledge or an inconsistency between



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their current knowledge representation and their experience. The third principle takes on a social context in that learning occurs through social negotiation, and that interaction between learners and their peers is a necessary part of the learning process (Vygotsky, 1978). Moshman (1982) classified three distinct interpretations of constructivism - endogenous, exogenous and dialectical – to which these approaches draw on constructivist learning.

Emphasis on the individual nature of each learner's knowledge construction process and the role of the teacher as a facilitator in providing experiences that are likely to result in challenges to learners' existing models is the key in endogenous constructivism. On the other hand, exogenous constructivism views that formal instruction, in conjunction with exercises requiring learners to be cognitively active, can help learners to form and refine their knowledge representations. Dialectical constructivism is the view that learning occurs through realistic experience, but that learners require scaffolding provided by teachers or experts as well as collaboration with peers. Hudak (2007) emphasizes that strong understanding of the learning theories is important in conceptualizing the learning objects to improve the learning process. She contends that a systematic plan for education should include consideration of the learning theories together with pedagogic frameworks to develop learning objects or environments using appropriate taxonomies of learning and instructions.

## 2.4 What is Virtual Reality?

The emergence of virtual reality (VR) since the last four decades has started to become more popular due to the mass media, which has coined buzzword of its apllications for the entertainment industry. Others terms such as virtual environment (VE), VR simulations, cyberspace, synthetic experience,

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virtual worlds, articificial worlds, artificial reality and new emerging ones are invariably mentioned in literature owing much to the creators and innovators of this technology. According to Sherman and Craig (2003) the definition of virtual reality is still in a flux because it is a new medium in educational training as researchers and users of VR naturally are having their own points of view precluding the precise meaning.

"Strangman and Hall (2003) defined virtual reality as a technology that allows users to explore and manipulate computer-generated, 3D multimedia environments in real time. On the other hand, Gaddis (1998) provides a short but concise definition expressing that VR is a computer-generated simulation of the real or imagined environment or world. While this broad definition offers great latitude in determining what may be considered a virtual world, it certainly does not conjure up images of what is commonly considered today's virtual reality." " A more pragmatic or practical definition that forms a generic model for virtual reality proposed by Gutierrez, Vexo, and Thalman (2008) comprises features that engenders computer-mediated experience, the objects in the virtual world are modeled using 3D model techniques and the system provides random interactivity."

Among these terms, virtual reality (VR) and virtual environments (VE) are used interchangeably. The use of the latter term VE actually predates the phrase VR (Sherman & Craig, 2003). In addition, many researchers did not favor the term VR because like artificial intelligence, it is ultimately unattainable. The appropriate term recommended is virtual environment (VE) that is defined as a computer-generated, 3D spatial environment in which users can participate in real-time. This definition is more pragmatic because VE can mean an immersive, encompassing worlds; augmentations (i.e., overlay) to the real world, and "through the window" worlds (i.e., non-immersive). However,

the term virtual reality continues to be used in industry, entertainment and education.

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### 2.4.1 Dimensions of Virtual Reality.

Diverse definitions of VR suggest that it is a technology that is not easily comprehended due to some underlying technological and psychological concepts. Some definitions are influenced by the technological dimensions while others are more concerned with psychological factors namely human experience. Traditionally, VR has typically been portrayed as a medium, like telephone or television rendering a technology-centric definition. The focus of VR is thus technological, rather than experiential; the locus of VR is a collection of machines, not the user (Waterworth & Waterworth, 2001). The presence or absence of the requisite hardware arbitrarily decides what is "VR" or "not–VR". However, the hardware-based definitions are not adequate to address the issue regarding the processes or effects of using these systems and most critical is their inability to provide a sound conceptual framework for evaluation or assessments.

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Human-experience approach has been adopted by recent studies in order to address the inadequacies imposed by the definitions of VR based on particular hardware. VR is considered a human experience according to Rauterberg (2004), implying the underlying closely-knitted relationship between perceiver and the virtual environment. Several researchers have identified the many aspects, characteristics, and properties of VR along this premise. "Zeltzer's (1992) unit cube model for characterizing virtual environments identifies three essential components, namely autonomy (human control), interaction (real-time control), and presence (bandwidth of sensation) that all such systems must have,



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and three dimensions or properties that can be used to compare virtual environments." Autonomy refers to the extent to which objects can respond to events and stimuli (both from each other, the environment and the user); interaction indicates the degree of access to the parameters or variables of an object. A measure of the fidelity of sensory cues that engenders a subjective sense of "physical presence" or "direct experience"' is called presence. The integration of Zeltzer's autonomy and interaction dimensions converges into interactivity dimension.

"Sherman and Craig (2003) outlined four key elements of VR experience namely virtual world, immersion, sensorial feedback, and interactivity." The first element refers to an imaginary space manifested through a medium and the second element denotes the sensation of being in an environment; can be purely mental state or can be accomplished through physical means. "The third element is the essentially ingredient that provides direct sensorial feedback namely visual, haptic, and others based on users' physical position." " The fourth element refers to the ability of VR to respond to user actions. Thurman and Mattoon (as cited in Mohler, 2001) proposed a model for differentiating different types of VR based on three dimensions, namely integration, interface and verity. Integration of the user in the virtual environment is claimed to be an essential part of VR. It focuses on how human beings are integrated into the computer system, culminating into "total inclusion" with VR. The concept of interface for VR is such as the interface disappears, permitting the user to interact directly with the virtual world. This interface dimension describes how the user interacts with environments, ranging from a scale ranging between natural and artificial." Verity is a measure of 'true to life' of the virtual world representing either real world or abstract concepts such that a high scale of integration of the user into the environment equates to immersion.

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Central to the learning and training in the virtual environments in terms of human experience is the concept of presence and immersion. "According to Slater and Wilbur (as cited in Gutierrez et al., 2008), presence is a state of consciousness, the (psychological) sense of being in the virtual environment. In other words, a coherent environment synthesized from the sensorial inputs – images, sound, tactile feedback – is realized allowing the user to perform some activities by means of interaction." This psychological state is achieved when the user is conscious, deliberately or not, of being in the virtual environments. A possibility also arises in that a person playing a video game knows that the world presented is not real, but s/he consciously acts as though it was real. "Gutierrez et al. (2008) posit that the state of presence is realized when people behave in a VE in a way that is close to the way they could behave in a similar real– life situation." Users can react in many different ways in a carefully crafted virtual environment that induces higher involvement during learning or training. They can experience sadness or happiness depending on the images, sounds, and other kinds of feedback that were synthesized into a coherent setting. However, the level of realism for each input relies on the intended training outcomes where, for example, in surgical simulation the high accuracy of haptic feedback overrides the image resolution; however, in the case of simulating an orchestra the realism of 3D graphics has a lower priority for the sense of presence.

Immersion in the virtual environment can be defined as an "intense feeling of self-location within the computer-generated reality with which the user interacts" (Cronin, 1997). Immersion can be considered as the product of the match between the technologies and the subjective feeling of involvement experienced by the user in the interaction process. The effects resulting from being immersed in VE have significant impact in learning or training. On the human factor premise, the subject-object distinction between users and what they learned disappears. Immersion in virtual world removes the interface allowing learners to cross the subject-boundary that exists between machine and

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human. Immersion also enables non-symbolic interaction with the world using what Bricken (1991) calls the "natural semantics". This kind of interaction allows learners to interact with object and actively experience phenomena in the VE in ways that are more than those commonly used when interacting with other computer-generated environments.

Interactivity is the extent to which users can participate in modifying the form and content of a mediated environment in real time (Steuer, 1992). Educational technologists argue that learners must interact with the environment for learning to occur. Some even suggested that interactivity is a more important factor of learning than immersion for some kind of tasks. This is attributed by close link between perception and action. Perception of the real world is closely linked to the action possible i.e., interactivity and it is posited that interactivity in VE will lead to a type of perception very similar to that of the real world, inducing a sense of presence. "Similarly, Dalgarno and Lee (2010) emphasize that immersion should not be treated as a unique property but as a product resulting from the interaction between representational fidelity (i.e., visual realism and object motion) and the types of activity available in the VE that leads to a strong sense of presence. In line with this argument, Gutierrez et al. (2008) added another factor that they believe very important in inducing presence which is user involvement." " They caution the importance to distinguish involvement and presence as in real life a person can be present, for example in a stadium watching a game, but not involved. Ultimately, it is the content of the VE that induces a sense presence such as playing a video game, whereby users will feel as though they are in the real world and will get isolated from reality despite using a non-immersive system. A practical implication for instructional designers and teachers is that novel training environments can be designed and built using affordable technology, but training contents have to be appealing and interactive allowing users to get fully engaged during training process.

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### 2.4.2 The Categorization of Virtual Reality.

The immersion dimension as explicated by Cronin (1997) forms the basis in categorizing VR systems based on the degree of immersion. Three VR systems have been classified as *"fully-immersive*, *semi-immersive* and *non-immersive"* VR systems. A fully-immersive VR system typically comprises a head-mounted display (HMD) unit that allows the user to be completely isolated from the physical world outside. Semi-immersive VR system implies that the user is partially immersed in the VE, usually achieved by different types of so called 'workbences' and 'reach-in' displays. The non-immersive VR system is also known as Desktop VR that is made up of a common and least expensive hardware configuration typically found in a standard desktop personal computer. It offers no feeling of immersion on the part of the user.

Moore's (1995) categorization of VR systems states that virtual reality falls into three major categories: text-based, desktop and sensory-immersive VR. These categories incorporate a very wide range of technologies with each quite distinct pedagogical issue. Text-based VR involves real-time environments described textually on the Internet where people interact by typing commands and communicate by typing messages on the computer keyboards. Desktop VR is an extension of interactive multimedia system involving 3D objects that enhances the experience of interactive multimedia without being totally immersed. The combination of appropriate hardware, software and concepts that enables user to interact with a 3D computer-generated "world" materializes a system called an immersive VR.

A description of VR systems by Fitzgerald and Riva (2001) indicates that VR can be presented in at least five ways: Desktop VR, Fully Immersive VR, CAVE, Telepresence, and Augmented. Their descriptions of Desktop VR and Fully-immersive VR are similar to Cronin's and Moore's. The CAVE (Cave Automatic Virtual Environment) provides the illusion of immersion by


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projecting stereo images on the walls and floor of a room-sized cube. Several persons wearing lightweight stereo glasses can enter and walk freely inside the CAVE. This solution is suitable for multi-user collaborative environment, sharing the same experience at the same time. Telepresence system allows users to influence and operate in remote site in real time. Users' observation of current situation is done by means of remote cameras and actions executed via robotics and electronic manipulators. Augmented reality does not create a totally artificial environment; it adds to user's sense of what is already there by enriching the real world with a complementary virtual world.

From these categorizations, VR systems vary considerably depending on many technological components such as hardware and software configurations, modality of interaction, internet-enabled, single or multi-user interactivity, and embedded multimedia components in the 3D worlds. The mixture of these components may induce different levels of immersion and presence in the VE with some possibility of collaboration. The right choice of VR system for learning relies on many factors by appropriate matching between VR features and educational factors such as learning contexts, learners' characteristics, learning styles, knowledge domains and pedagogical factors. Prudent steps to choosing a particular technology will invariably involve the identification of intended training outcomes or objectives, the background of the trainees, and the training materials. Synthesizing these elements coherently together with the technical and practical considerations can help designers to select the appropriate technology in developing a training program that is not only effective but also affordable. More important, proper training and learning applications developed from this technology can provide meaningful learning opportunities to pupils.

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## 2.5 The Application of Desktop Virtual Environment as A Spatial Training Platform

"Of late, virtual environment has become the focus of much research studies on training users to navigate in large-scale virtual places. This is not surprising given the long tradition of the use of the technology in military and in aerospace training applications – domains that require highly trained personnel who perform risky, hazardous duties. The creation of realistic, responsive virtual training environments enables personnel to acquire skills without being exposed to certain dangers that potentially occur in real environments (e.g., handling of toxic materials, fire-fighting drills, and hostage-rescuing simulations). Most of these studies stemmed from the needs to simulate training that involves orientating or navigating in large environments, which through virtual environments can be conducted in smaller labs; thus, these synthetic settings eliminate the use of real locations, which often could be hard or even impossible to achieve (Dünser, Steinbügl, Kaufmann, & Glück, 2006). Using VR, researchers will be able to create exact stimuli and conditions for all participants or to vary certain environmental variables in real-time, thus empowering researchers more control over experimental settings.

All the early research has mainly focused on specialized training environments, which invariably involves prohibitively expensive, highly technical systems — beyond the reach of many organizations, but recent development in computing technology has opened up new, vast possibility for using the same technology through affordable, less-cumbersome desktop tools (Ausburn & Ausburn, 2004). "A major recipient of this technological advantage is educational sector where teachers, instructors and lecturers can now partake in research activities to improve students' academic performance. Research on using synthetic, simulated virtual environments is being intensively pursued to help seek better ways to teach technical, engineering and scientific concepts to students (Valizadeh, Noroozi, & Sorial, 2010, p. 3)."

Findings have been mixed — promising outcomes juxtaposing discouraging ones — but the overall majority of the findings is quite encouraging, which provides the impetus to continuing research on this technology for educational purposes, primarily to improve instructional delivery.

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"One important intelligent construct that has received serious attention of late is spatial ability, and this intellectual trait has been demonstrated to be a strong predictor of success in technical and scientific domains (Sutton, Williams, & McBride, 2009b)." " More important, this crucial cognitive ability plays important and dominant role in humans' routine activities like negotiating turns while driving, arranging home furniture or navigating streets. Various training settings have been developed to improve spatial ability by harnessing the capabilities afforded by the virtual reality technology; however, most of these training conditions are based on immersive systems, which are expensive and cumbersome. Capitalizing on the ubiquitous, affordable computing platform, desktop virtual reality technology serves as a potent alternative for developing spatial training applications that bring in together some of the training benefits offered by high-end immersive systems: interactive, responsive, and programmable synthetic environments."

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Besides these potentials, there is a widening gap (in terms of theoretical basis and practical pursuit) as evidenced by most of the training applications developed thus far that did not use well-established instructional design methods to ensure efficacious training platforms. "Apparently, to some people, the technology used is viewed to be the sole enabler of training success – a misconception that could lead to costly mistakes. It is not technology *per se* that causes learning, but rather the '…the instructional method that causes [it]' (Mayer, 2005, p. 6). To achieve optimal training success, the development of training platform must involve intertwining the theoretical aspects of how people learn (i.e., cognition) and the design of instructions for educational



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practice (i.e., instructional setting)." This symbiosis relation is aptly emphasized by Mayer (2002, p. 55) who sees relation between cognitive theory and educational practice as a two-way street — the one that is both intertwined and reciprocal.

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## 2.6 The Application of Constructivist Learning Theory to the Desktop Virtual Environment for Spatial Training

The evolving nature of learning theories seems to take place uncannily at the same breath and pace with the development of technologies, in particular the information and communication technology. Recent learning theories are categorically constructivist in nature that can guide instructional designers to create conducive learning environments by using information and communication technology, notably the virtual reality. According to Sala and Sala (2005), virtual reality (VR) or virtual environment (VE) systems have been featured very prominently in recent educational literature demonstrating their effectiveness in learning and training. "Many researchers recommend the use of information technology in particular VE to foster constructivist learning conditions through the creation of computational tools and virtual representations that students can use and interact (Atkinson, 2009; Coppola, 2005; Cunningham, 2006; Dalgano & Lee, 2010; Dalgao & Harper, 2004; DeMiranda & Folkestad, 2000; D'Souza & Bunt, 2000; Winn et al., 1997;" Ziemek, 2006).

Computational tools that complement human memory and intelligence are made available as learners interpret experience to refine their mental models (Zaretsky & Bar, 2005). Constructivism theory fits very well in a virtual environment where learners can engage in experiential learning through interactions with learning objects that continually facilitates the construction and



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refinement of knowledge (Atkinson, 2009; Zaretsky & Bar, 2005). Peripheral learning is replaced by deep learning through interactions between students and phenomena to technological instantiation of learners themselves and reality itself. Many researchers such Atkinson (2009), Dalgarno and Lee (2010), Dalgarno and Harper (2004), Dede (1995), Winn et al. 1997, and Zayas (2001) attributed the successful educational applications of VR to three contributing factors, namely immersion, interaction and engagement.

Virtual environment can help realize the concept of learning by doing or experiential learning as emphasized by endogenous interpretation of constructivism by its ability to provide a real-time and interactive 3D simulation of real world or abstract concepts. Learners can explore and interact with the virtual artifacts representing specific knowledge base without direct instruction. Through these engaging activities, learners can regulate their cognitive functions, mediate new experience with existing mental models, and become aware of the current knowledge structure. The interactivity and control within the virtual environment enables learners to see immediate results, as they create mental models or try out their ideas about the concepts modeled (Rieber, 1992). "A virtual environment can also provide multiple perspective, themes, or interpretations to the problem being examined by the learners. A unique feature in virtual environment is its ability to provide unlimited number of viewpoints of the 3D environment, enabling learners to view virtual objects from all three dimensions, as well as both internally and externally." " The relationship of multiple perspectives and multiple representations is one of the causes and effects within cognitive constructivism (Dalgarno & Harper, 2004)." "Experiencing multiple perspectives for a particular event provides students with relevant materials necessary to develop multiple representations. These multiple representations provide students with various routes from which to retrieve knowledge and the ability to develop more complex schemas relevant to the experience."

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"Exogenous constructivist learning stresses the importance of direct instruction to assist learners to create their own mental model of the ideas to be learned with the supporting activities (Dalgarno & Harper, 2004)." " These activities enable learners to refine their knowledge representation through testing their ideas and understanding. In the learning environment, virtual environment can be utilized in two ways either by embedding smaller virtual environments (i.e., discrete 3D models of objects) into instructional learning resources or making the virtual environment as an interface to the instructional resources." The latter part may involve learners working through the conventional learning resources and periodically perform activities within the virtual environment, prior continuing with the subsequent sections of the materials. "Learners can have the flexibility to revisit any of the virtual environments (i.e., 3D models) to refine their mental models for a situation that demands further investigation." This learning environment differs with the endogenous constructivist learning environment in that the latter educational setting has a greater degree of system control over the selection and sequence of activities.

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The educational setting based on dialectical constructivism principles will facilitate the undertaking of authentic activities by learners together with the provision of scaffolding through interactions with their peers, mentors or experts (Dalgarno & Harper, 2004). Experience provides the activity upon which the mind operates. In addition, knowledge construction is enhanced when the experience is authentic so the learner can construct an accurate representation of the "real" world, not a contrived world and may construct mental structures that are viable in meaningful situations. Virtual environment, in this regard, can represent a 3D representation of a problem in the form of visual and auditory realistically with a high degree of realism that mimics the real world. In this setting, learning activities can also be explored socially, such that group members and the teacher negotiate the meaning and application of each step of



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the learning process. Each learner will attain a personal understanding of the concept learned; however, this personal understanding will be mediated by the social setting of the classroom. The scaffolding component as emphasized by dialectical constructivism may take various forms of system-generated support within the virtual environment ranging from simple system-based help facility initiated by learners or an intelligent agent that monitors learners' progress in the learning process.

Most of the early studies were based on fully-immersive VR systems of the high-end VR technology characterized by special hardware and peripherals. Of late, low-end VR technology based on desktop virtual environment has emerged from recent studies advocating its use in training. "Advanced development in desktop computing has made possible the creation and delivery of highly complex 3D models along with a host of multimedia features. "Familiarity and experiences in using the desktop computer allows easy and better control when students migrate to desktop virtual environment." " Citing Buchanan's work, Dalgarno and Lee (2010) stress that desktop VR can be harnessed through 'co-opting' the tools students use for desktop communication and entertainment to help them learn better." In contrast, using immersive environments can induce physical and psychological stresses associated with heavy head gears and relatively low resolutions of stereoscopic glasses. Though devoid of the naturalistic interfaces, the perceptual expectancies and natural affordances suggest interactions can be supported (at the low end of the interactivity spectrum) in desktop virtual environment by browser maneuvers via a computer mouse (Zayas, 2001). The application of desktop virtual environment is further expanded with the latest development and proliferation of the internet allowing the distribution of 3D environments, which are capable of being explored by multiple learners together on their desktop computers at separate locations.

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The other two important factors – interaction and engaging – as pointed by Winn and his colleagues (1997) are attainable in desktop virtual environment rendering it as an effective learning tool. A major finding from Brady's (2004) study suggests that interaction is a more important facilitator of learning than immersion for some kind of tasks. The engaging factor can be facilitated with programmed behaviors (i.e., animations) of learning or training objects. It appears that there exists a pedagogigal ground for the adoption of desktop virtual environment in delivering a learning environment based on the principles of constructivist theory of learning." The discussion on this section concurs with the suggestion made by VR proponents such as Dalgarno and Lee (2010), Dalgarno and Harper (2004) and Winn (1993), claiming that constructivism as the best learning theory on which to develop educational applications of virtual reality.

The discussion of the related literature namely education, cognition, and technology revealed that there is an array of interrelated issues pertaining to engineering drawing learning. Empirical evidence suggests that spatial ability is prerequisite in learning the subject matter and that this ability is amendable to training. However, developing a training application to enhance this ability entails deep understanding of learners from educational and cognitive perspectives that underpins the importance of constructivist learning where learners can actively engage in knowledge construction in authentic training environment. Instructional materials used must be carefully crafted based on required training objectives guided by sound pedagogical principles. To support the training process, the learning or training environment should engender a high level of interactivity supported with scaffolds: the former to induce greater involvement in training, and the latter to help ease learners' cognitive efforts in completing a task. In essence, desktop VR could be utilized as a promising training platform for spatial training by harnessing the latest technological

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improvements of the desktop computing, which provides training opportunities that are normally associated with high-end, immersive VR technology.

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## 2.7 Summary

Basic engineering drawing comprises orthographic views representing the principle faces of an object and on certain occasions requires a 3D representation through isometric view. The ability to interpret and to produce these drawings entails the cognitive capacity to visualize and manipulate 2D representations of corresponding 3D objects. This ability is generally referred to as spatial ability, comprising a number of dimensions or sub-abilities. The development of this ability is shaped by the interactions between several biological and environmental factors spanning one's entire life that ultimately mould her or his spatial skill. The environmental perspective stresses on the amenability of this cognitive construct to training or interventional treatments. Several methods have been employed to improve spatial ability, namely spatial visualization and mental rotation that have achieved some degree of success. Desktop virtual environment provides a natural means in realizing a new, novel platform for spatial training; a training platform that engenders constructivist (i.e., interactive, instructive and supportive) environment that helps in meaningful knowledge construction.



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# CHAPTER 3

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# RESEARCH METHOD

## 3.0 Introduction

Two research paradigms were used involving an explanatory research survey and experimental research in this study. The former method was used to explain existing phenomenon that involves students' perceived ability to learn engineering drawing or self-efficacy in learning the subject matter that might be influenced by demographic and academic factors, namely gender, spatial experience, and mathematics achievement. A survey pertaining to students' perceived ability to learn engineering drawing involving 355 secondary schools students of mean age 15.5 years was carried out at 19 secondary schools in Peninsular Malaysia. The latter method involved an experimental intervention using the classical control group posttest pretest research design with the main aim to investigate the improvements in spatial ability (spatial visualization, mental rotation accuracy, and mental rotation speed) before and after spatial training.

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More important, the experimental method sought to examine the main effects of training condition (interaction-enabled mode vs. animation-enhanced mode vs. conventional mode) and gender (female vs. male) in training outcomes, and the interactions between these two independent variables or factors. Stratified random sampling was used to randomly assign 33 secondary school pupils of mean age of 16.5 years into two experimental groups and a control group. The experimental procedures involved pre-testing of spatial

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ability, spatial training in three different conditions, and post-testing of spatial ability. The study also sought to examine the transfer of training to solving engineering drawing task and to identify factor(s) that is(are) influential in the training transfer. Statistical analyses used in this study were *paired sample t*-test, *2-way ANOVA,* and *Multiple Linear Regression* to test the research hypotheses of the study.

## 3.1 Conceptual Framework of the Study

The study undertaken was based on the framework shown in Figure 3.1 that essentially comprises two main stages, namely an exploratory survey research and an experimental research. "The former served as the precursor to the overall study whereby it had revealed prevailing issues surrounding the subject of interest prior to further detailed investigation. The latter constitutes the major part of the overall research involving detailed and focused examination of a phenomenon informed through the latter's findings and related literature." A review of current engineering graphics and visio-spatial literature encompassing both local and international contexts paved the way for the researcher to conduct the survey research that focused on the perception in the learning of engineering drawing at the foundational year among a group of pupils who enrolled in the class of the subject matter.

Students' demographic, namely gender, mathematics achievement and spatial experience were the independent variables; and the perception of their ability to learn engineering drawing was the dependent variable of this quantitative survey research. The perception of learning of the subject matter was divided into several categories based on the topics of learning in the foundational engineering drawing curriculum. A major interest was the perception of learning the topics categorized as high spatial, namely multi-view

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orthographic drawing and isometric drawing as these two types of drawing constitute the basic engineering drawing that students must be able to produce and/or interpret. "Researchers and instructors stress that the ability to draw and interpret orthographic and isometric drawings is vital without which the teaching and learning of the subject matter will be compromised (Olkun, 2003; Taylor, 1980; Yue, 2007). An engineering drawing task based on the understanding of these two views was then developed to be used in the experimental research, serving as the dependent and criterion variable in the later stage of the study. Among the independent variables, spatial experience was further investigated particularly on spatial ability of students given its primacy that influences the learning of the subject matter. Thus, the focus of the research was on training spatial ability, namely spatial visualization and mental rotation to determine the extent of training improvement." The independent variables of the experimental research were the training condition and gender, and the dependent variables were spatial measures namely spatial visualization and mental rotation, and engineering drawing task performance.

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A review of literature on digital technology, theories of learning, and cognitive and psychometric science helped the researcher to develop the training environment, training setting and training objects. The final part of the research involved examining the impact of spatial ability improvement on solving basic engineering drawing task. For this later stage of the research, the researcher also sought to investigate the spatial factors that are critical in the engineering drawing task performance where spatial ability components, namely spatial visualization and mental rotation after training served as the predictor variables and the criterion variable was the performance of engineering drawing task. Figure 3.1 on the following page shows the conceptual framework that conceptualizes all the relevant variables and their relationships in the survey and experimental research undertaken.

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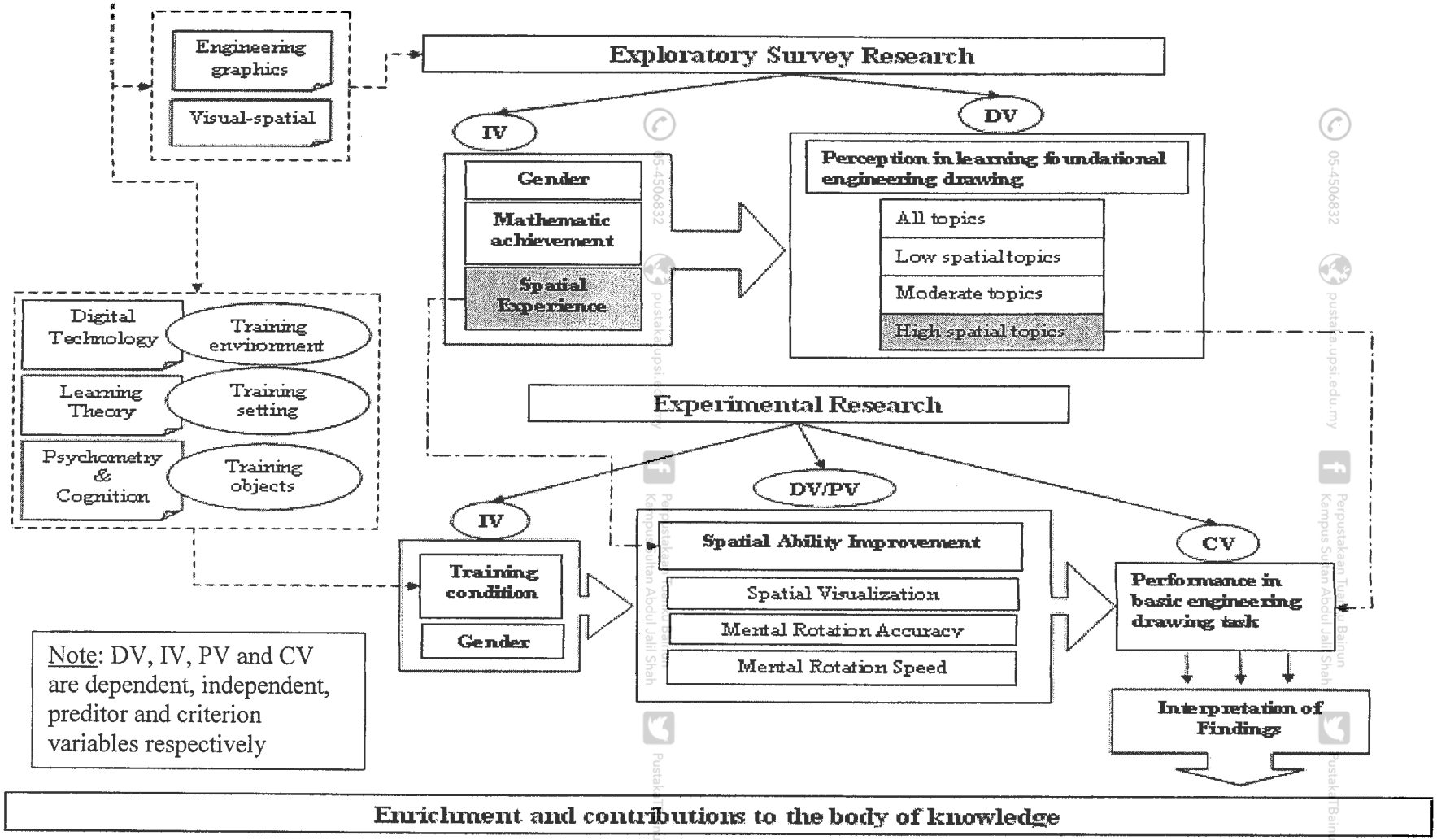



*Figure 3.1.* The conceptual framework of the survey and experimental research

## 3.2 Research Method

The research method of the study was based on a quantitative research study comprising a survey research based on explanatory paradigm and an experimental research using an interventional program, which essentially is based on the *Triangulation Software Development Method.* A survey research is beneficial especially in an effort to learn a particular phenomenon in a population of interest by examining the relationships among factors (MITRE, 2005). In this study, the survey research involved the examination of a phenomenon, namely students' perceived ability to learn engineering drawing at the foundational year, which were dependent on students' demographic and background. From the literature review, the independent and dependent variables had been clearly defined; the models of their expected relationships were tested using the data and information elicited from the survey on the phenomenon being studied.

In this study, the experimental research was conducted immediately after the survey research, which involved the implementation of an interventional spatial training involving specific spatial exercises to enhance students' spatial ability or skills. "According to Ross and Morrison (2004), an experimental research is required in order to examine the effects of environmental change, referred to as "treatments", that entails designs based on standardized procedures to hold all conditions constant except the independent (i.e., experimental) variables. The interventions or treatments help examine a phenomenon in a controlled setting. The independent variables are manipulated accordingly to observe their effects on the dependent variable. The researcher has direct control over the laboratory conditions and manipulation of the independent variables to study the phenomenon occurring in the dependent variable. The laboratory experiments undertaken are well suited to the designed

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research project involving relatively well-defined concepts and propositions involving individuals or small groups (Ross & Morrison, 2004).

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Examination on the effects of an interventional program that involved spatial training through specifically design spatial tasks to improve students' spatial ability, namely spatial visualization (SV) and mental rotation (MR) skills was the main focus of the experimental research. In other words, this part of the research study aimed at investigating the malleability of this ability, which is important in learning engineering drawing to training. Premised on this focus, differential effects on students' SV and MR improvement gains that were attributed to different training conditions and gender were also investigated." Transfer of spatial training to solving engineering drawing task (i.e., transfer from knowledge construction to knowledge application) was also examined to predict the significant, critical factor(s) responsible for such transfer.

### 3.2.1 Introduction to the Survey Research

The first research hypothesis (see Section 1.5, p. 17) was dealt with by means of an explanatory survey research. This research hypothesis constitutes three sub-hypotheses for the survey research in order to address the demographic of students, namely gender, spatial experience, and mathematics background. This survey was carried out prior to developing the treatment program by sending questionnaires to all schools involved with the teaching of engineering drawing as one of the technical elective subjects available in the Malaysian secondary schools system. The researcher visited the participating schools and, with the help of the subject teachers, administered the questionnaires to the pupils who volunteered to take part in this survey. Prior to

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conducting the survey the researcher had to strictly follow the procedures of the Malaysian Ministry of Education in getting the approval and consent. Relevant school agencies and authorities were first contacted through phones and formal letters were sent (after getting the verbal agreement) to respective schools that had agreed to take part in the survey.

### 3.2.1.1 Background of the Survey Research

The rationale of the survey research was to examine factors that may influence students' perceived ability or self-efficacy in learning engineering drawing at the foundational year (i.e., at the Form Four level) of the Malaysian secondary schools. The Malaysian school system consists of primary and secondary levels: the former encompasses a period of six years and the latter seven years. Students of the secondary school at the Form Four level are equivalent to the tenth graders of the American school system. The instructions of engineering drawing course span two years, commencing at the Form Four level where the fundamental concepts, theories, and techniques are covered. Core topics for that year of learning are geometrical constructions, orthographic projection, axonometric projection, and 2D Computer Aided Drafting.

The second year of the engineering drawing study is at the Form Five level (i.e., at the 11th grade), which deals with advanced topics of engineering drawing such as intersections of solids, development drawings, and 3D Computer Aided Design. The first year of the engineering drawing course involves nine topics or units; for the purpose of this research, these topics were divided into several categories in order to study the varying perceptions of learning ability among the selected pupils. Several factors have been identified

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to be critical in shaping students' perceived ability to learn the subject matter, namely spatial experience, mathematic achievement and gender.

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As learned from the related literature, one main research question (see Section 1.4, p. 16) with the corresponding one main research hypothesis (see Section 1.5, p. 17) were formulated to address the issues as discussed in the main body of the preceding section. In addition to the research question and hypothesis, the study undertaken also sought to identify the factor(s) among the three variables (i.e., spatial visualization, mental rotation accuracy and mental rotation speed) that may have strong predictive power to explain the variation in the perceived ability of students in learning the subject matter through statistical analyses utilizing a series of multiple regression models

### 3.2.1.2 Method of the Survey Research

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This section details the demographics of the participants that participated in the survey research, instruments utilized for data collection, and procedures adhered to in conducting the administration of the survey questionnaires in the study.

#### 3.2.1.2a Participants of the Survey Research

A total of 355 pupils of Form Five Level (i.e., 11th. graders) comprising 103 females and 252 males who had studied the engineering drawing subject at the foundational year participated in the study. "The average age for all the respondents was 15.5 years. The survey sample of 355 students with males

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overwhelmingly outnumbering females reflects the typical gender distribution in Malaysian schools where males constitute the majority in taking technical subjects such as engineering drawing. The percentages of students drawn from northern, southern, central, and east coast states of Peninsular Malaysia were 26.4%, 25.3%, 27.1%, and 21.2," respectively.

The geographical distribution provides a balanced representation in terms of secondary schools that are involved in engineering drawing instructions. All students involved were briefed and assured that their participation was voluntary and each pupil was required to read and sign the consent forms indicating their agreements to the terms and conditions prior to the administration of the questionnaires. An example of the self-administered questionnaire is shown in Appendix 13.0 that contains items pertaining to students' demographics and perceptions in learning the subject matter.

### 3.2.1.2b Instruments of the Survey Research

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A self-reported questionnaire designated as *Students Perception Questionnaire* (SPQ) was "designed by the researcher to elicit information regarding students' demographics and background including mathematics achievement and their perceived rating of their ability to learn the nine topics of engineering drawing subject – all that are consistently reported to be crucial in learning technical graphics (Olkun, 2003). The validity of the instrument was verified based on expert judgment as reviewed by an expert in engineering drawing instructions. A nine-item Likert-scale questionnaire elicited respondents' responses along five available choices ranging from 1 (*extremely difficult*) to 5 (*extremely easy*) in rating their perceived ability to learn engineering drawing (see Appendix 14.0)." The average score for each item

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measured indicates the level of students' perceived ability to learn a specific topic of the subject matter. The summation of the scores for the nine items represents the perceived ability to learn all topics in engineering drawing.

Higher scores reflect that students perceived their ability to learn the topics are generally high. On the other hand, low scores indicate their low perceived ability to learn these topics. "The Cronbach Alpha procedure was used to establish the internal consistency of the instrument because this statistical technique provides a measure of reliability that can be obtained from one testing session or one administration of a questionnaire" ( Leech, Barret, & Morgan, 2005). Reliability coefficients of .79, .80, .71, and .69 were computed for perceived ability to learn all topics, high spatial content topics, orthographic and isometric topics, and low spatial content topics, respectively." All the reliability coefficients were above and within the threshold value of .7, establishing a reasonable measure of the instrument's reliability.

The "*Spatial Experience Questionnaire* (SEQ) in Malaysian language was adopted from the McDaniel, Ball, & Kolloff's (1978) English version, which was used to measure participants' level of spatial experience. The SEQ comprises a list of 25 spatial activities such as drawing, map reading, and playing 3D games. Students were asked to rate their participations in spatial activities on a Likert-type scale of four options: 1 (*never*), 2 (*occasionally*), 3 (often), and 4 (*very often*) (see details in Appendix 15.0). The scores were then summated and averaged to reveal participants' mean scores of their engagement in spatial activities. The categorization of the participants' level of spatial experience is based on the global mean score: high spatial experience participants were those who scored above this value and the remaining were deemed as low spatial." Internal consistency for the Spatial Experience Questionnaire (SEQ) by the same procedure described previously was carried out rendering a reliability coefficient of .89.

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### 3.2.1.2c Procedure of the Survey Research

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Any application to conduct educational research study in public schools in Malaysia entails formal communication with the relevant agencies, namely the Education Planning and Research Department (EPRD), and the State Educational Departments (SEDs). The former normally requires a draft of the research proposal from a researcher prior to approving her or his study. Once a formal letter of approval is secured from the EPRD, a formal letter is followed requesting consent from the SEDs to allow such a study to be conducted at selected schools. Principals of the selected schools were then contacted by phone calls and followed by mail upon getting the approval letter from the SEDs. The administration of the survey questionnaires was carried out by visiting the schools during school free periods to prevent any disruptions of school activities. Co-curricular activities and other school priorities cropping up at the last minutes hampered some of the efforts to conduct the survey on a larger scale. Nonetheless, the sample adequately represents a balanced proportion in terms of gender and geographical distribution.

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The administration of the questionnaires was carried out in the presence of the researcher at the selected schools to enable the collection of first-hand information on prevailing educational setting. All the participating schools possessed almost similar instructional materials and contents, gender composition, teacher to student ratio, and teachers' teaching experience, thus providing equivalent educational setting for the research that minimized the potential internal threats to the validity of the study. All the students involved were given ample time to read and to respond to the questionnaire throughout the survey exercise. Subject teachers were also present to help the researcher in the administration of the questionnaire.

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This study employed a quantitative survey approach through the administration of questionnaire comprising two sections. The first part of the questionnaire consists of five items to elicit demographics and background information of the respondents (see details in Appendix 14). The second part consists of nine items for respondents to rate their perceived ability to learn engineering drawing. Prior to pilot testing, the questionnaire was reviewed by a panel of experts consisting of two lecturers from the same institution where the researcher is working; the two experts have extensive experience in engineering graphics and computer-aided design (CAD) instructions. In addition, one of the experts was also one of the authors of the engineering drawing textbook used by students at the national secondary schools. Their opinions were also elicited to categorize the nine topics of engineering drawing course into three main groups, namely topics that were deemed low, moderate, and high in terms of spatial contents. The spatial content categorization of the topics was conceptualized as the degree of cognitive effort (i.e., spatial visualization skills) students need to use when learning the topics. Previously, no such instrument was available for this purpose and the categorization was purely based on expert judgment. The process of this categorization was performed by reviewing all of the learning contents of each unit by mapping them to the levels of spatial skills required for learning.

Topics with high spatial contents were "Orthographic drawing, Isometric drawing, and Auxiliary views. The moderate spatial content topics were Sketching, Geometrical construction, Oblique views, and Computer Aided-Design (I). Topics deemed having low spatial contents were Introduction to Engineering Drawing, and Lettering and Lines. Orthographic drawing and Isometric drawing from the topics of high spatial content formed a special interest as these two units represent the basis of an engineering drawing. Data elicited from the questionnaire to measure participants' perceived ability to learn

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engineering drawing course were collapsed into several categories: all topics, high spatial content topics, moderate spatial topics, and low spatial content topics, thus rendering four criterion variables to be utilized in the regression analysis.

Pearson's correlations were computed for all the variables to reveal the significance and strengths of their interrelations, namely perceived ability to learn, gender, previous mathematic achievements, and spatial experience. Multiple regressions were conducted to analyze the predictions using perceived ability to learn as the criterion variable, and gender, previous mathematics and spatial experience as the predictor variables." A stepwise regression procedure was also run using the same variables to identify the critical factors that would have significant predictive power that could explain the variation in the perceived ability to learn.

### 3.2.2 Introduction to the Experimental Research

This research utilized a true experimental pretest posttest between-group design to compare three groups of participants in terms of the extent of training effectiveness, differential training outcomes based method of training and gender, and training transfer. True experimental design is an ideal design for maximizing internal validity through random assignment of subjects to treatments, thereby eliminating any systematic error that might be associated with using intact groups (Ross & Morrison, 2004). The experimental research was conducted using interventional treatments involving two experimental groups and one control group. The former two groups were exposed to experimental or treatment conditions controlled by the researcher in the

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laboratory environments by manipulating the variables of training elements of interest whilst the latter group trained in conventional condition. The use of experimental conditions entailed the implementation of an interventional program or application that was designed and developed by the researcher. All the three groups received equal training in terms of training practice duration, training materials or contents, and instructions in spatial visualization and mental rotation. In essence, controlling extraneous factors is vital to ensure that the internal validity of the experimental research and the ability to infer causality is strengthened (Ross & Morrison, 2004). Potential experimenter bias was also controlled in this experimental study whereby the researcher took turn with the subject teachers in supervising the training sessions of the three different groups throughout the study.

### 3.2.2.1 Population and Sampling of the Experimental Research

The target " population for the study was the Form Four secondary students (i.e., 10th. graders) taking engineering drawing (*Lukisan Kejuruteraan*) subject in Sekolah Menengah Kuala Kubu, Selangor, Malaysia. There were only three classes in the school conducting engineering drawing course at the foundational year involving 98 pupils comprising 36 girls and 62 boys. Prior to training, the subject teacher was contacted by a phone call to convey the purpose of the study and a verbal agreement was secured. A formal letter was sent to the school's principal to seek permission for the experimental treatments (see details in Appendix 6.0). Students were briefed on the purpose of the study and assured that their participations were voluntary and they were allowed to drop out at any stage during the study. Having understood and agreed the terms and conditions, they signed the letters of consent (see details in Appendix 7.0) indicating their

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voluntary participation." The experimental treatments were carried out outside normal school hours beginning of the semester to ensure that training would not be disrupted by any classroom activities and/or extra-curricular classes, which normally take place in the middle and at the end of school semester.

Pure probabilistic random assignment could not be used in this study due to higher number of males compared to females reflecting an imbalance on a characteristic such as gender of a sample. Creswell (2005) recommends stratification to be used when a simple random sampling procedure would yield fewer participants in a specific category (e.g., females) precluding rigorous statistical analysis. In the experimental study, the assignments of students into the three groups were thorough stratified sampling procedure where the sample was divided into some specific characteristics (e.g., gender) and then, using proportionate allocation technique to draw proportionate representation of females and males into groups. "This involved "blocked design" in which participants were randomly assigned within a block of trials while keeping sample sizes equal across conditions. In the interventional treatments, the 36 female volunteers were divided into 12 blocks of 3 participants each. Then the researcher randomly assigned each of the three female participants within a block to one of the three experimental conditions. Likewise, the 62 male volunteers were divided into 21 blocks of 3 participants each. Then the researcher randomly assigned each of the three male participants within a block to one of the three experimental conditions. The identification of the participants according to the assigned conditions was recorded (see details in Appendix 8.0). In addition, this sampling method minimizes the possibility of history, selection, and interactions between selection and other threats." Spatial training or treatments were carried out using three laboratories outside their normal classroom lessons spanning a period of six weeks.

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### 3.2.2.2 Research Design of the Experimental Research

This study employed a multi-factorial pre-test post-test experimental "(3 x 2) design procedure comprising two independent variables; namely training method (3 levels: interaction-based, animation-enhanced, and control) and; gender (2 levels: female and male). The dependent variables in this study were performance measurements in spatial visualization, mental rotation and engineering drawing task. This experimental design was carried out using probabilistic sampling based on stratified sampling procedure that randomly assigned participating students into two experimental groups and one control group. The first experimental group trained in the spatial trainer where interaction with virtual training objects was enabled (termed as interaction)." The second experimental group trained in the spatial trainer where interaction with virtual training objects was disabled but the objects could be animated (termed as animation).

The control group trained using similar contents of training materials albeit in printed form. Instrumentation threat exists as a potential threat in most experimental studies, but the experiments conducted utilized the same instruments for the pre- and post-test keeping the instrumentation threat to a minimum. The details of the development of the interactive desktop virtual environment spatial trainer (DVEST) are elaborated in Chapter 4 focusing on the framework for the development of the spatial trainer. The framework was conceptualized through the review of the current literature pertaining to the theories of learning, spatial cognition, psychometric testing and educational technology.

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### 3.2.2.3 Pre-Testing, Spatial Training and Post-Testing in the Experimental Research

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The prototype of the interactive desktop virtual environment spatial trainer (DVEST) is developed on the desktop computer platform. The deployment of this trainer for treatments was at a secondary national school involving 98 pupils. In this school, both control and experimental groups were established and maintained throughout the study. The experimental research involved three main, consecutive stages that began with the testing of spatial ability measures prior to treatment, followed with spatial training activities, and post-testing of similar spatial ability measures and testing of engineering drawing task were carried immediately after spatial training. The experimental stages are elaborated in the proper order as follows:

#### 3.2.2.3a Pre-testing in the Experimental Research

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Pre-testing of students' spatial visualization (SV) and mental rotation (MR) abilities for the control and experimental groups in the selected school prior to treatment or training phase was carried out in the first week. "The instruments utilized in the study to test students' spatial ability namely mental rotation and spatial visualization were based on the online Mental Rotation Test designed by Chay (2000), and the Spatial Visualization Test developed by the Mathematics Department of Michigan State University for the Middle Grade Mathematics Project (MGMP-SV) (1981), respectively. Computerized versions of the two instruments were developed and integrated into the spatial trainer (DVEST) to facilitate measurement and data collection of the two components of spatial ability." These two spatial ability instruments have been used very extensively in many studies involving interventional or training programs to

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investigate training outcomes focusing on spatial visualization and mental rotation abilities.

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### 3.2.2.3b Training in Spatial Visualization and Mental Rotation

The deployment of the interactive desktop virtual environment spatial trainer (DVEST) in the selected school to treat the experimental groups spanned six (6) consecutive weeks to ensure targeted students would have enough time to acquire such skills as other studies have documented that after students had participated in spatial activities for at least three weeks, their basic spatial ability significantly improved (Clements & Battista, 1992). "The nature of the spatial training was task-specific practice effect sample style as it focused only on two spatial factors, namely the mental rotation and spatial visualization. The more direct and task-specific the training methodology, the more likely it is to improve participants' spatial performance ( Baenninger & Newcombe, 1989; Vandenberg & Kuse, 1978)." Training sessions were distributed over several weeks in the study as spaced practice or practice spread out over time will be ideal for long-term retention as suggested by Druckman and Bjork (1991).

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The DVEST has been designed specifically to train students to harness their mental rotation ability and spatial visualization ability. Students in the experimental groups were instructed and guided to use the DVEST by engaging in spatial activities specifically designed to tap on the two skills of SV and MR. " These skills are essential when they begin to learn the basic principles of engineering drawing namely orthographic and isometric representations that requires cognitive processing of similar mental operations associated with spatial visualization and mental rotation. The instructional contents or training materials were divided into six modules or units categorized under two main

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themes namely mental rotation and spatial visualization. Spatial training comprised six training sessions evenly distributed over six weeks with each training session lasted for two hours. The participants first trained using simple spatial exercises in weeks one and two, followed by spatial exercises of moderate difficulty in weeks three and four, and finally progressed to complex and difficult exercises in weeks five and six." The weekly interventional treatments were carried out in three computer laboratories that are detailed as follows:

*Week 1:*

Prior to spatial training, all the participants were briefed with regards to the proper procedure in using the specific modules of the spatial exercises. In particular, participants in the experimental groups were given 45 minutes of training practice to familiarize with the computerized training environment. This familiarization exercise was important to ensure that all participants gain enough exposure in using the 3D training virtual environment. The finding of Vila, Beccue, and Anandikar's (2003) study shows that the influence of gender factor in VR navigation is salient during initial exposure and will attenuate with further practice. This is particularly crucial in computer-mediated training involving both genders where training performances are not attributed to practice alone but mediated by computer experience where in general females rather than males were perceived to lack this ability (Robert & Bell, 2000b).

Participants receiving mental rotation training in interaction-based condition in DVEST used the first module of mental rotation comprising a series of simple exercises, each requiring them to determine the correct angle and direction of rotation of a comparison object to match, in terms of orientation,

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with a target object about a single axis. This first experimental group used the mouse-controlled interface using buttons which control the positions and orientations of the virtual camera in relation to the virtual objects to produce a sense of interaction such as moving, translating, zooming (in and out), rotating, walking, rolling, pitching and panning. The second experimental group that trained using the same spatial exercises in DVEST with the aid of animations that when requested will show the correct rotational trajectories of the comparison objects to match the target objects. The control group performed the same spatial exercises using printed worksheets that include solutions for the exercises in graphical form.

*Week 2:*

Participants that received spatial visualization training in interaction-based DVEST used the first module of spatial visualization comprising a series of spatial exercises each showing a simple stack of regular blocks where one needs to determine the correct number of blocks that are in contact with a target block. Participants in this group could interact with the stack of block or objects through mouse-controlled interface to view the training objects from multiple angles or perspectives. The animation-enhanced DVEST group trained to solve the same spatial exercises with the aid of animations in the spatial trainer that highlight the actual blocks that are in contact with the target block by moving them away one by one from their initial positions and then moving these blocks back to their original locations. These animations helped facilitate spatial understanding of the arrangements or configurations for each exercise. The control group performed the same spatial exercises by means of printed

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worksheets that include diagrams or figures depicting the solutions for the exercises.

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*Week 3:*

The treatment or training procedure in mental rotation tasks in the first week was repeated again covering moderate level of difficulty involving spatial exercises each requiring the participants to determine the correct angle and direction of rotation of a comparison objects to match with a target object. However, the degree of difficulty was higher as solving the spatial tasks involved rotating about two axes rather than one axis.

*Week 4:*

The treatment or training procedure in spatial visualization as in the second week was repeated again covering moderate level of difficulty involving spatial exercises, each requiring the participants to determine the correct number of blocks that were in contact with a target block arranged in a stack configuration. The degree of difficulty is higher than previous tasks as the participants need to count more blocks that were in contact with a given target block. In other words, the arrangements of the stacks of blocks in this training were more densely packed requiring greater mental effort to visualize the components in a given stack. In other words, the spatial tasks had to be solved by investing greater mental efforts by the participants; the efforts would entail spatial thinking based on the sub-skill of spatial ability.

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*Week 5:*

The treatment or training procedure in mental rotation as in the first week and third week was repeated again covering complex level of difficulty involving spatial exercises each requiring the participants to determine the correct angle and direction of rotation of a comparison object to match with a target object. The tasks were more difficult than previous tasks as solving would involve rotation of complex objects through more than one axis of rotation. The difficulty of the tasks was also raised by having virtual novel objects which students were unfamiliar with that make the tasks more difficult both in terms of perceptual processing and mental rotation.

*Week 6:*

The treatment or training procedure in spatial visualization as in the second week and fourth week was repeated again covering complex level of difficulty involving spatial exercises, each requiring the participants to determine the correct number of blocks that were in contact with a target block. The difficulty of the spatial tasks was higher than previous tasks as solving involve counting the blocks in contact with a target block in a stack configuration of complex arrangement. The level of difficulty was also manipulated by having gaps or voids in the stack demanding greater mental effort to visualize the individual blocks that were in contact or not in contact with a given target block.

To avoid any external threats to the experimental study, the two experimental groups and control group received similar spatial training exercises

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n similar setting in terms of practice duration, time and day of training, and training contents. The researcher and two subject teachers that had been briefed and trained in the experiments played the role of facilitators by taking turn in supervising among the three groups to prevent any biased treatments. This recommendation is in line with Ross and Morrison's (2004) caution that multiple validity threats can be severe to preclude meaningful results. If such a case occurs, an experiment needs to be redone which will add extra cost to the experiment in terms of time and money.

### 3.2.2.3c Post-testing in the Experimental Research

At the end of the training session in the sixth week, participants in the experimental and control groups were tested with the same computerized SV and MR instruments as outlined in Section 3.1.2.2a Pre-testing. The measurements at this stage provide the posttest measures that were used to compare if there were any statistical significant differences in the mean test scores before and after training that would reflect performance gains in the tasks related to spatial visualization and mental rotation. The summary of activities spanning a period of six weeks is shown in Table 3.1 on the following page.

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Table 3.1

*Pre-testing, spatial training and post-testing*

| *Week:* | *Activities:* | *Description:* |
|---|---|---|
| 1 | Pre-testing of spatial ability measures, administration of consent forms, and task familiarization with the spatial trainer. | Pre-testing of spatial visualization and mental rotation abilities prior to training. |
| | Mental rotation training involving simple tasks. | Involves mental rotation tasks about an axis only. |
| 2 | Spatial visualization training involving simple tasks. | Involves spatial visualization tasks involving stacks of made up of few blocks. |
| 3 | Mental rotation training involving moderate tasks. | Involves mental rotation tasks about two axes. |
| 4 | Spatial visualization training involving moderate tasks. | Involves spatial visualization tasks involving stacks of a bigger number of blocks (i.e., arrangements were denser). |
| 5 | Mental rotation training involving complex tasks | Involves mental rotation tasks about three axes. Also include novel, unfamiliar objects. |
| 6 | Spatial visualization training of complex task | Involves spatial visualization tasks involving bigger number of blocks of complex configurations. Also include gaps or voids. |
| | Post-testing, and administration of questionnaires. | Post-testing of spatial visualization and mental rotation abilities after training. Administration of questionnaire was performed to measure students' perception on training effectiveness, spatial cognition and trainer's usability. |

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### 3.2.2.4 Students' Performance in Engineering Drawing Task

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According to Scribner and Anderson (2005) "the primary goal of educators in a design or drafting course is to teach beginning students the fundamental concepts of orthographic projection. In this study, a spatial task was employed that served as a measure of student understanding in orthographic projection where discernment in such a task is reflective and indicative of students' ability to perform in engineering drawing (Kang, Jean, Chung, & Chung, 2004). Hence, a basic engineering drawing task in the form of a multi-view orthographic drawing was assigned for each student in order to determine her or his level of performance that could be explained by the enhanced spatial ability accrued during the spatial training in mental rotation and spatial visualization in the three conditions." In this particular task, all the participants were asked to solve the problem individually by completing a series of incomplete 2D orthographic views representing a 3D object (see details in Appendix 9).

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This task was derived from one of the exercises in the engineering drawing textbook under the orthographic views unit. The task was moderate in difficulty to avoid the risks, if any, due to floor and ceiling effects. Scoring of the task was based on the correct line drawing representing the edges of planes representing the correct views of the object with a maximum score of sixteen (see details in Appendix 9.0). "Solving this task entailed mental manipulation and transformation between 2D and 3D mental pictures that was afforded by the acquired SV and MR skills. Previous studies conducted by Olkun (2003) and Scribner and Anderson (2005) have shown that spatial ability, namely spatial visualization and mental rotation would be evoked when learners engaged in interpreting and/or producing 2D representations of a given 3D object".

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### 3.2.2.5 Instruments of the Experimental Research

The instrument used in the research to test students' mental rotation was the computerized version developed by the researcher based on "Chay's (2002) online version, which is a web-based mental rotation test that is retrievable at http://www.uwm.edu/People/johnchay/mr3.21e5.html. This instrument was based on the Vandenberg and Kuse's (1978) mental rotation test. An example of the test item is illustrated in Appendix 10.0. The electronic test version comprises 30 evaluation items, each composed of a target figure and a comparison figure. The comparison figure can be either a congruent figure or an incongruent figure that is positioned at various degrees of orientation. All the 30-item questions are made up with one-half having congruent figures and the remaining half consisting of incongruent figures as the correct answers. The scoring procedure yields maximum possible correct scores of 30," and all questions are randomly presented to avoid an order effect.

Total time taken to complete the test was also recorded for each participant. This test is presumed to load on the mental rotation factor of spatial ability and has been shown to be one of the spatial ability tests least likely to be confounded by analytic processing. "Internal consistency and construct validity of the instrument is high based on the reported Kuder-Richardson reliability coefficient of 0.8. Performance measure of this cognitive construct is both based on accuracy and speed (Linn & Petersen, 1985; Yilmaz, 2009). The scores of this test served as both the pretest and posttest measurements of mental rotation accuracy and speed." A time limit of two-and-half minutes for the 30-item mental rotation test was strictly enforced to restrict possible analytical processing.

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The instrument used in the research to test students' spatial visualization was the computerized version developed the researcher based on the Middle Grade Mathematics Project-Spatial Visualization Test (MGMP–SV, 1981). The MGMP-SV comprises 32 multiple-choice items, each with five options. The test contains 10 different types of items. The types of representations used are as follows: (a) two-dimensional flat views, (b) three-dimensional corner views, and (c) a "map plan," which depicts the base of a building using numbers within squares to indicate the number of cubes to be placed on each spot. The test includes tasks such as finding either flat or corner views of "buildings", adding and removing cubes, combining two solids, or applying the notion of a "map plan". The reliability of this instrument is reasonably high having Cronbach's alpha coefficient ranging from .72 to .88. Although the test was not timed, students were explicitly instructed to complete the test within 30 minutes. A few examples of the test items are illustrated in Appendix 11.0.

The attitudinal instrument to elicit information regarding students' perception in using the interactive desktop virtual environment spatial trainer (DVEST) contains 12 items where they were required to rate each item along a Likert-type scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Items in the questionnaires were adapted and modified from the survey instrument used by Mackenzie and Jansen (1998) for assessing multimedia computer-based instructions. The initial draft of this questionnaire was translated into Malaysian language by a language expert to establish syntactical and grammatical consistency. The same draft was reviewed by a multimedia instructor for assessing its appropriateness in the context of spatial training in the virtual environment (see details in Appendix 12.0).

The instrument used to test students' performance in basic engineering drawing task involved solving a series of views of orthographic projection of a

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given isometric representation of a 3D object. An isometric drawing of a 3D object is depicted along with three views, namely plan, front, and side views that are not fully complete. Participants were required to complete the details of the given three views. Grading is based on the accuracy of drawing 'the missing edges' representing the faces of the views. The test item was extracted from the engineering drawing textbook used in Malaysian secondary schools. Participants were required to complete this task within a 20-minute time limit. A sample of this task is shown in Appendix 9.0.

### 3.2.2.6 The Testing of the Research Hypotheses of the Experimental Research

Determining to what extent the statements in the research questions is valid by means of significant testing is the fundamental feature in any experimental research design with emphasis on investigating the differences of the measurements of factors before and after an intervention. All together, there were six research hypotheses that had been formulated in the study. Each statement was tested to determine to what extent the statement holds at some level of significance indicating whether what have transpired after spatial training based on certain conditions really occurred, and not due to chance. The first research hypothesis (i.e., $H_i$) for the survey research was tested using the *Pearson correlation* procedure. The second research hypothesis (i.e., $H_{ii}$) was addressed by means of *paired sample t-test* procedure. The test is used to compare the values of means from two related samples, for example in a 'before and after' scenario (Leech et al., 2005). In the study, it was imperative to examine the differences between the levels of spatial visualization and mental rotation of the participants before and after spatial training. The third and forth research hypotheses (i.e., $H_{iii}$ and $H_{iv}$) were tested using *two-way analysis of*

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*variance* (2-way ANOVA). Factorial ANOVA is used when there are two or more independent variables (each with a few categories or values) and a between groups design (Leech, 2005). This statistical procedure allowed the analysis of the effects of spatial training based on the independent factors or variables (i.e., training condition and gender) on the dependent variables (i.e., spatial visualization and mental rotation). This procedure also allowed the analysis of possible interactions or interplay between the independent variables and dependent variables attributed to the levels of the former that may cause differential effects on the later.

Similarly, the statistical procedure of 2-way ANOVA was also used to address the fifth research hypotheses (i.e., $H_v$). Again, the statistical procedure allowed the analysis of the effects of the independent variables, namely groups that received different training methods and gender on the dependent variable (i.e., performance in basic engineering drawing task). In addition, interactions between the two independent factors (i.e., group and gender) and the dependent variables were investigated to check whether training outcomes were equivalent or not across all levels of the independent variables. *Post hoc* tests would be used once significant interaction effects were detected.

*Multiple Linear Regression* (MLR) procedure was utilized to test the final research hypothesis (i.e., $H_{vi}$). "This procedure has the purpose of predicting a dependent or criterion variable from several independent or predictor variables (Leech et al., 2005). This regression technique is appropriate in exploring relationships among multiple independent variables as demonstrated in this study involving spatial visualization, mental rotation accuracy, mental rotation speed, and gender; and their individual effects and overall effect on the criterion variable (i.e., engineering drawing task performance). Effectively when testing a hypothesis, an optimal regression

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equation will be established indicating the influence of each factor in determining the variance accounted for in the criterion variable." In addition, the pre-determined significance level chosen will indicate the factors that are significant in explaining the variance accounted for in the basic engineering drawing performance in this study.

### 3.2.2.7 Statistical Analyses of the Experimental Research

All data collected were entered into the Statistical Package for the Social Sciences, SPSS version 18.0 for the statistical analysis. In total, there were four statistical procedures utilized namely independent sample *t*-test, paired sample *t*-test, two-way analysis of variance (2-way ANOVA), and Multiple Linear Regression (MLR). Prior to spatial training, the pretest measurements of spatial visualization and mental rotation were used to test significant differences between the genders using independent samples *t*-test. Differences between the mean scores of both genders were analyzed for significance at the predetermined level of .05. After training, the pretest and posttest measurements of spatial visualization and mental rotation were used for the paired *t*-test analysis utilizing the mean scores of the tests. Differences between the mean scores before and after training were analyzed for significance at the predetermined level of .05.

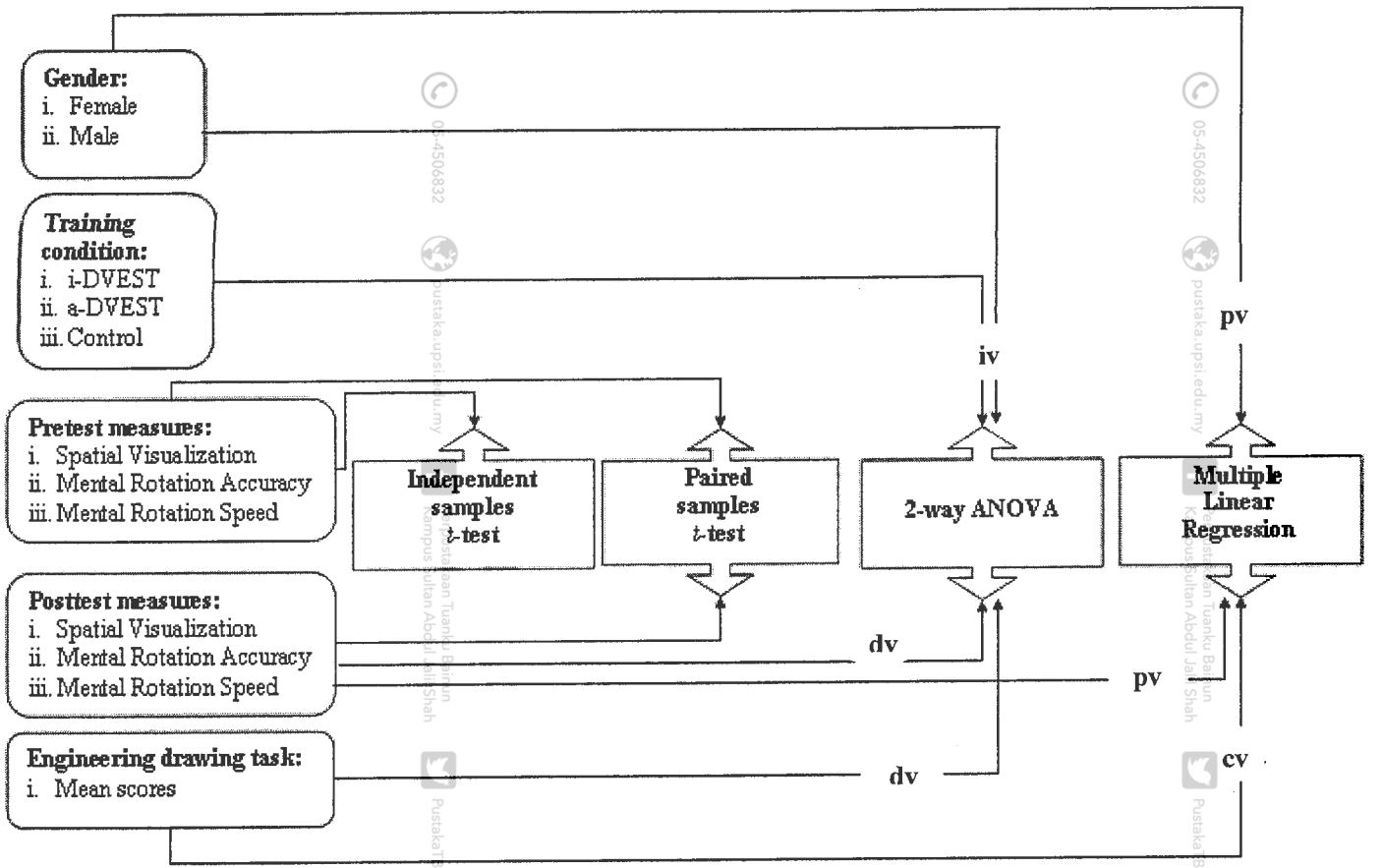
A series of two-way analysis of variance (2-way ANOVA) were the statistical models used that are based on the general linear model (GLM). "The first model involved training method (3 levels: interaction-based, animation-enhanced, and control) and gender (2 levels: girls and boys) as the independent variables, and the posttest measures of spatial visualization and mental rotation as the dependent variables to test significant main and interaction effects of the

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independent variables on the dependent variables. The second model of the 2-way ANOVA used the same independent variables (i.e., training method and gender) as before but the dependent variables were the mean scores of engineering drawing task." The assumptions of independence, normality, and homogeneity of variance were investigated prior to using this statistical model. All significance testing were set at the .05 significance level.

The examination on the influence of spatial ability measures (i.e., spatial visualization and mental rotation) and gender in predicting the performance of the basic engineering drawing task was performed through Multiple Linear Regression procedure. This procedure treated these factors as the predictor (independent) variables and the mean scores of basic engineering drawing task as the criterion (dependent) variable. The proper use of this statistical model entailed rigorous testing on several assumptions, namely multicollinearity that could result from high correlations among some set of the predictor variables. Figure 3.2 on the following page summarizes all the factors or variables used in the models for the statistical analyses employed in the experimental research study.

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Note:
cv = criterion variable,
dv = dependent variables,
iv = independent variables,
pv = predictor variables.

*Figure 3.2.* The statistical models for the analyses in the experimental research

## 3.3 Summary

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The research study utilized two research paradigms through a survey research study and an experimental research study to examine issues related to students' perceived ability (i.e., self-efficacy) in learning engineering drawing and spatial ability training, respectively. The examination on students' perceived ability in learning engineering drawing was addressed by means of an explanatory survey research involving 355 students drawn from 19 secondary schools. The independent variables investigated in the survey research were gender, spatial experience, and mathematics achievement, and the dependent variable was students' perceived ability. On the other hand, an experimental research was utilized to investigate the extent of improvement in spatial ability (i.e., spatial visualization and mental rotation) after spatial training involving 33 secondary school pupils. Differential effects in training improvement attributed to training method and gender were also studied. Final phase of the study involved the examination on training transfer from spatial training domain to engineering drawing task domain. The components of spatial ability and gender that were significant for the training transfer to solving engineering drawing task was also predicted using appropriate statistical modeling. For the whole research, the statistical inferential procedures used in the analyses of data were independent samples t-test, paired samples t-test, 2-way ANOVA, and multiple linear regression.

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# CHAPTER 4

# THE DEVELOPMENT OF THE SPATIAL TRAINER

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## 4.0 Introduction

This chapter deals with the background that rationalizes the development of the spatial trainer in enhancing spatial ability namely spatial visualization and mental rotation that are important to ensure learning in domains requiring such abilities or skills. The use of the desktop-based virtual environment using the virtual reality modeling language (VRML) helped develop the spatial trainer (DVEST). A conceptual framework for the development of the spatial trainer was built upon the knowledge on the current theory of learning and psychometric testing of spatial thinking. The former helped create a learning environment by utilizing three constructivist elements to provide endogeneous, exogeneous, and didactic training that enabled the participants to train effectively.

On the other hand, the latter guided the appropriate selection and the development of training objects that when used during training would tap on specific mental processes; thereby eliminating unnecessary engagement of spurious training acitivities. Spatial training employed was primarily based on a series of exercises of mental rotation accuracy, mental rotation speed, and spatial visualization ranging from simple through moderate to complex tasks. Completing the spatial exercises entailed the participants to read the instructions carefully and then they were required to choose the appropriate spatial solutions, entailing them to interact with the virtual training objects and/or to use the animations. All the interactions performed by each participant in the experimental study was carried out through the Cartona's client interface (a third party's application viewer), which was controlled by a pc mouse.



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## 4.1 The Background of the Development of the Interactive Desktop Virtual Environment Spatial Trainer (DVEST)

Spatial visualization and mental rotation are two important sub-abilities of the multi-faceted spatial ability deemed vital in technical and scientific domains such as architecture, engineering, computer-aided design, and graphics. Their importance in these areas of learning has been confirmed by findings highlighting strong correlation between these abilities and the domains of learning (Besterfield-Sacre, Atman, & Shuman, 1997; Jayasree, 2003; Kang, David, Jean, & Jan, 2004; Strong & Smith, 2002). Spatial ability constitutes an important dimension in the multi intelligence theory expounded by Gardner (1983) under the spatial intelligence category. Visuo-spatial ability is one of the general intelligence components that in essence represent individuals' ability to form mental images and make inferences of the environment through visual perception and spatial cognition.

Emerging technologies have made great stride in learning and training development and desktop virtual reality or environment is a recent, new 3D-graphics technology making strong presence in educational and training fields of late. Wider adoption by educational and training communities has been propelled by the development of Virtual Reality Modeling Language (VRML), engendering the creation of virtual environments that are deliverable over the World Wide Web (Beier,2000). Continually improving desktop computing that provides affordable hardware and software, which owes to the open-standard, non-proprietary programming language, has made desktop virtual environment as a promising learning and training platform.

The utilization of these technologies for training must be carefully considered in relation to two vital issues: one relating to the needs for appropriate level and style of contents; and the other relating to the needs to use the right software and delivery mechanisms (Beier, 2000; Fernie & Richard, 2003). More important, the development of any training program or application must be informed through current theories of


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learning to ensure that the implementation of such a training program will be able to achieve its stated goals through optimizing training or learning process (Hudak, 2007). Spatial training to improve spatial visualization and mental rotation must be planned accordingly using appropriate or authentic tasks tapping on the required cognitive functions. Training must be designed such that it evokes spatial strategy – rather than analytical strategy – when solving spatial tasks. For this reason, the researcher developed the spatial trainer (i.e., a web-based application) comprising instructional activities in the form of exercises enhanced with virtual environment containing virtual training objects was designed along the constructivist principles to improve the participants' spatial visualization and mental rotation.

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## 4.2 Theoretical Considerations in the Development of the Spatial Trainer

The topic of spatial training has been deliberated extensively in the literature covering interventional programs or applications developed to train users in spatial tasks. Some of these training programs were too generic to enhance skills and knowledge in specific components of spatial ability. Others have been found to be lacking strong theoretical framework to inform the design of the training applications, prohibiting efficacious use of the interventional programs. In this study, the researcher adopted a theoretical approach informed through a review on the literature of current theories of learning and psychometric testing. The former guided the development of instructional setting or training environment that helped participants maximize their learning or training potentials whilst the latter ensured that relevant spatial tasks were put in place using appropriate learning objects or training tools than tapped on relevant spatial ability. Coupling these two factors had facilitated the development of an effective spatial training application. This study only focused on training two components of spatial ability, namely spatial visualization mental rotation.

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The design of the training application was based on the framework espoused by the constructivist view of learning. Dalgarno (2001) outlines three broad principles of this view based on studies by Kant and Dewey for the first principle, Piaget for the second principle, and Vygotsky for the third principle. The first principle informs that an individual forms his or her own representation of knowledge and there is no particular 'correct' representation of knowledge. The second principle prescribes that learning occurs when learners uncovers a deficiency in their knowledge representation or an inconsistency between their current knowledge representation and their experience during active exploration. Learning takes place within a social context is the third principle of this constructivist view. In this study, the researcher had adopted the three broad principles in formulating the approaches to the training process. To explicate the intricacies of the interpretation, Mossman (as cited in Dalgarno, 2001) categorized constructivism into three distinct classes, namely endogenous, exogenous, and dialectical constructivism. Endogenous constructivism stresses on individual nature of each learner's knowledge construction process relegating the role of teachers to facilitators. Exogenous constructivism underscores the formation and refinement of knowledge representations through learning by instructions with support from exercises entailing active cognition. Dialectical constructivism espouses learning through realistic experience coupled with essential scaffoldings.

The appropriate use of training or learning objects to be utilized was informed by reviewing the items in the psychometric test battery. Spatial ability tests have been developed by many cognitive psychology institutions and are utilized as part of intelligence and employment assessments. These tests possess strong validity and reliability measures for the cognitive-psychological constructs such as spatial visualization, mental rotation, spatial perception, and other spatial measures. Appropriate items of the tests were first reviewed, and then they were developed into training objects as part of the instructional materials that participants used for spatial training.

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This would help ensure effective training using these artifacts or objects through carefully planned instructional activities that would tap on relevant cognitive skills rather than generic skills. The development of the training objects for spatial visualization was based on test items under the category of 'count touching blocks' that measures the ability of individuals to visualize forms in space and to manipulate them mentally (Wiesen, 2004). This ability is also a strong component of mechanical aptitude deemed vital in learning technical and industrial fields. For mental rotation training, the classical Metzler and Shepard's (1974) approach was referred to prior to developing the training objects and the tasks associated with them.

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## 4.3 The Conceptual Framework of the Interactive Desktop Virtual Environment Spatial Trainer

The next step in the implementation of the training program was the deployment of the training objects as part of instructional learning activities in an appropriate platform designed accordingly to the principles or views of constructivist learning theory. A desktop virtual environment was chosen capitalizing on two important criteria; three-dimensionality and practicality. The former is very important in engendering 3D-space learning environment that inherently is spatial and visual allowing training in spatial knowledge or skills that hinges on spatial properties and relationships of objects and space. The latter is more concerned with ease of development, implementation, and maintenance in typical Malaysian schools that are invariably constrained by limited financial budget. The terms virtual reality and virtual environment are interchangeably used to describe a computer-generated three-dimensional (3D) environment allowing real-time interactions by means of one of more control devices and involving one or more sensorial perceptions ( Ausburn& Ausburn, 2004; Shneiderman, 1993).

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Though lacking the immersion factor associated with high-end immersive virtual reality systems, desktop virtual environment has made significant impact in learning and training given the continually increasing processing capability of desktop computing, providing faster and better graphics delivery. Desktop VR technology emerges in several formats; but the affordable, easy to use format is the type that could generate interactive 3D environments under mouse control for intuitive interaction, which is suitable for general classroom use (Ausburn & Ausburn, 2004). Realism, flexibility, interactivity, and easy learner control of the screen-based environments offer great learning potentials for users in the desktop or unencumbered VR (Shneiderman, 1993). The development of open-standard, non-proprietary Virtual Reality Modeling Language (VRML) has spurred wider adoption of desktop VR, which is web-deliverable over the Internet for greater distribution. VRML is a language for creating functional and interactive worlds on the web where interaction and participation are typically achieved through a VRML plug-in for a web browser on graphics monitor under mouse control. The universal adoption by the Internet community has been propelled by the current version VRML 2.0 under the name VRML97 as an international ISO/IEC standard (Beier, 2004).

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The development of an interactive desktop virtual environment spatial trainer (DVEST) was carried out as a web-based application that constitutes a series of exercises pertaining to mental rotation and spatial visualization tasks involving comparison and target objects, and configuration of stack of blocks respectively. Each exercise consists of a question with several options that are presented in textual format, and training blocks are presented as virtual objects. Interactions with the virtual objects are performed through a mouse-controlled VRML interface. Animations of the virtual objects were also programmed in DVEST as a cognitive tool for assisting learners in the visualization and provision of correct spatial solutions. Feedback mechanism was also added to inform learners the incorrect or correct responses they made. The importance of immediate feedback to learning is vital since knowledge of results is necessary to correct mistakes and develop new plans.



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Dalgarno (2001) cautions the wholesale adoption of any particular constructivist interpretation in designing learning or training environment. The researcher drew upon a combination of elements from each view to produce a training environment that could optimize training effectiveness. Spatial exercises were composed of a series of questions requiring the participants to read carefully related instructions and statements prior to choosing the correct solutions. This method of training emphasizes the role of direct instruction to help learner to form their own mental model of the spatial arrangement of the tasks, aided by activities that allow learners to test and refine their knowledge representation. This setting establishes a training situation grounded on exogenous constructivist view. In choosing the correct solution to a particular problem, a learner can interact with the virtual training objects in 3D space by mouse control to observe spatial orientations and configurations from multiple views that helps the construction and refinement of her or his mental models of the spatial task. The active exploration process in this mode mirrors endogenous constructivist views emphasizing the active role of learners in learning process.

Training exercises are also supported with animations showing the correct spatial solutions to the spatial problems. The combination of feedback to inform learners the correct or incorrect status of the responses and animations constitutes a scaffolding mechanism in line with the dialectical view of constructivism to help learners to arrive at the final, correct solutions. The three training processes based on the constructivist views are fused into the training environment, providing learners a conducive setting that helps optimize training efficacy. Figure 4.1 on the following page illustrates the conceptual framework of the spatial trainer embedding these constructivist elements for spatial training of spatial visualization and mental rotation abilities.

A virtual environment is sometimes referred to as a *virtual world* or a *scene*. In this study, a simple desktop virtual environment (VE) as illustrated in Figure 4.2 was designed comprising a basic virtual world configuration namely the *3D objects* and the



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*manoevering/navigation* components. Additional component namely the *behavioral* element can be added to provide interactivity in the virtual environment. These provide the required basic functionalities of the spatial trainer as informed by the theoretical considerations elaborated previously to help the planning and designing of such an application. Figure 4.1 on the following page shows the integration of the digital contents in the spatial trainer, namely the textual environment ( HTML-coded) and the virtual scene (VRML-coded). In addition, a 3D object or component in the virtual scene could be 'manipulated' visually by means of maneuvering (navigation) in the space. The *behavioral* component in the virtual scene could be programmed to provide enhanced *interactivity* and *dynamic* responses. The dotted arrows in the Figure 4.1 denote the three training environments based on the three constructivist approaches: exogeneous, dialectical, and endogeneous.

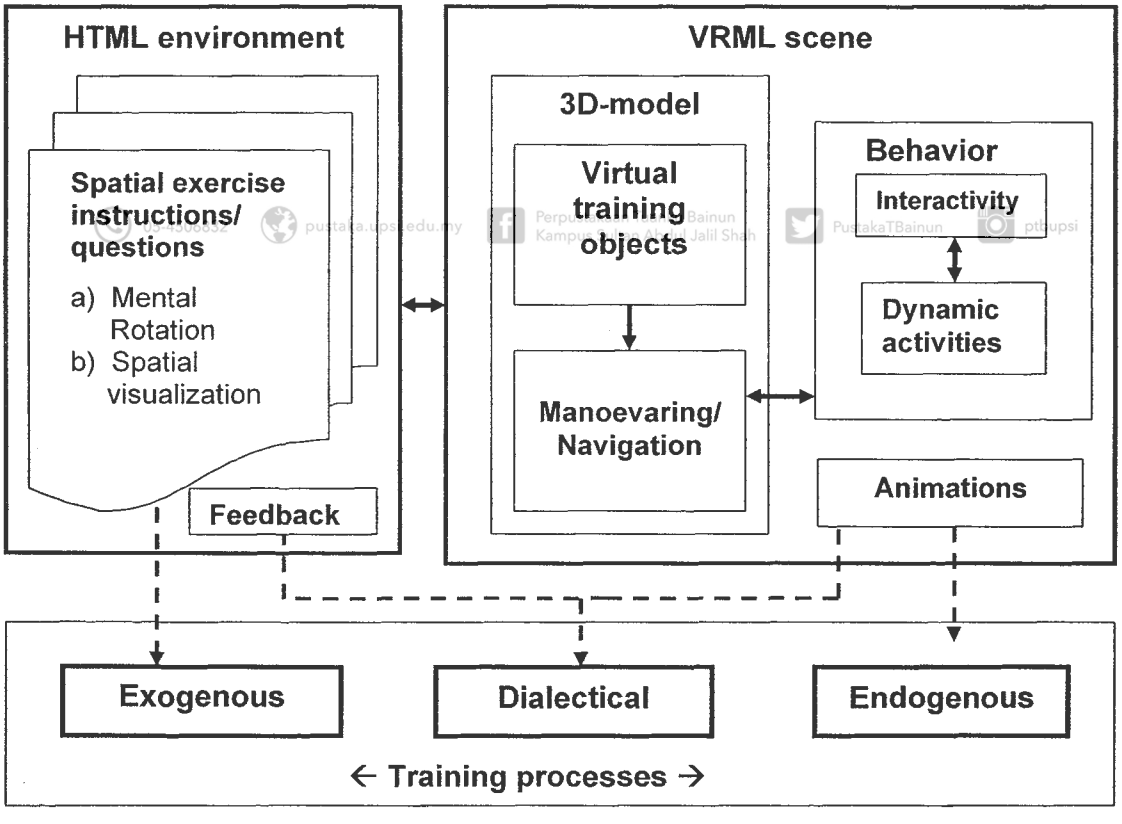



*Figure 4.1.* The conceptual framework of the spatial trainer (DVEST).



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The essential and distinct feature of the desktop VE is the inclusion of the third dimension, namely the '*z*' dimension providing the depth measure in addition to existing '*x*' and '*y*' dimensions. This in effect allows full definition of 3D space and objects reflecting the true real world scenario. The interaction engendered through navigation and maneuvering in the virtual world is the key element that clearly demarcates the desktop VE from the interactive multimedia environment. Passive viewing accorded by the latter is replaced by active exploration and interaction in the former, providing a measure of control for users. Engaging in active participation or exploration in the virtual environment coupled with a high degree of learner control stamps a mark of learning or training process based on the constructivist view. Maneuvers or navigations in the desktop VE refer to the perceived movements from one location to another in the 3D virtual scene made by the users. Essentially, the sensation of moving from one point to another in VE is made through the constant changes in the orientation and position of the virtual camera in relation to the virtual objects, which are hidden to the users. Maneuver or navigation in the virtual world can be viewed as a form of behavior involving both interactivity and dynamic activities based on the premise that when a user selects the course of exploration the computer will react accordingly to depict the appropriate view.

Changes in the desktop VE is induced by the behavioral element or component breaking down into dynamic activities and interactivity. Changes taking place in any parts of the desktop VE are referred to as dynamic activities. A special case of this involves the changing of the viewing perspective, which is part of the maneuvering (navigating) a component. Certain dynamic behaviors of virtual objects can be programmed to produce some responses or reactions when a specific action is executed. Effectively, the desktop VE is capable of acting and reacting in some unique fashion achieving a capability that is known as interactivity. The relationship between dynamic activities and interactivity is intertwined in that the former must be activated by some actions whilst the result of the latter manifests in the changes to the dynamic behaviors in the desktop VE.



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## 4.4 The Development of the Interactive Desktop Virtual Environment Spatial Visualization Trainer (DVEST)

The development of the DVEST prototype was structured based on two basic formats, namely HTML pages and VRML virtual objects description. The former includes all the menus for navigation on web pages, buttons for selected choices and animations, and instructional information in texts. The latter forms the desktop virtual environment or scene containing virtual training objects; interacting with these objects is performed through mouse-controlled VRML client interface. The DVEST essentially contains two training modules, namely spatial visualization exercises and mental rotation exercises. The former was used to help participants to train in spatial visualization when undertaking spatial tasks designed to tap on this ability. The latter was employed for mental rotation training when participants tried to solve spatial tasks by performing mental rotation in their minds.

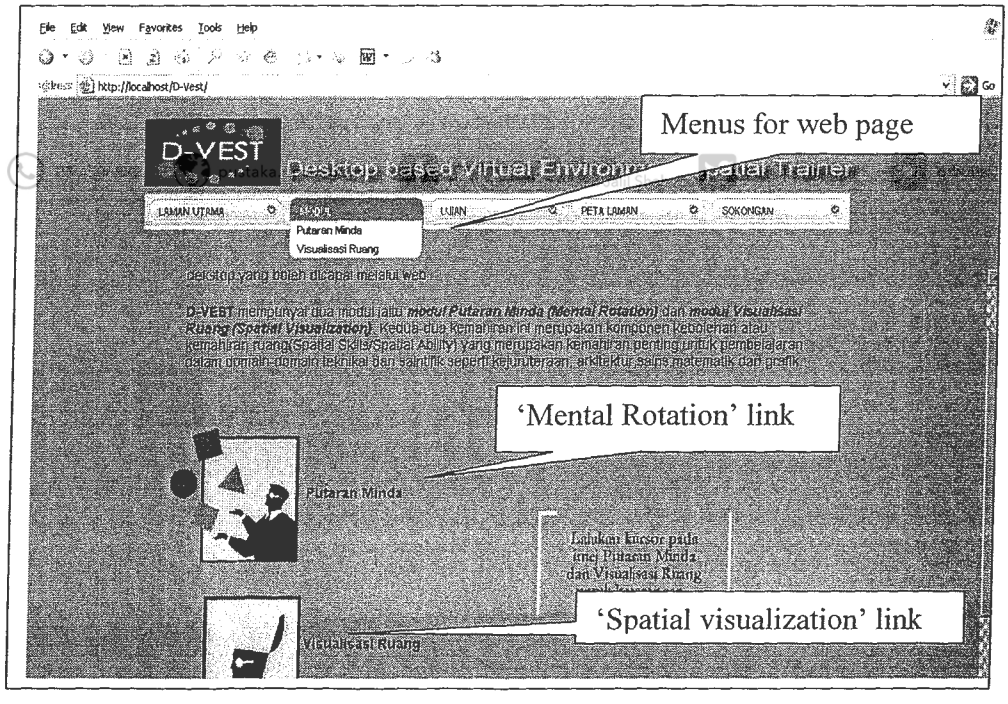



*Figure 4.2.* Main page of DVEST with links to spatial visualization and mental rotation modules.

Demonstrations on the correct procedures or steps to perform the spatial exercises were also designed and put in place in the spatial trainer. These demonstrations were important for the participants to get themselves informed and focused on using the correct mental operations when solving the spatial tasks. Figure 4.3 shows the mental rotation page containing a brief introduction regarding the mental rotation training and hyperlinks. The participants could begin the spatial exercises by clicking the tutorial hyperlink or learn the basic operations of solving the tasks by clicking the demonstration hyperlink (see Figure 4.3 below).

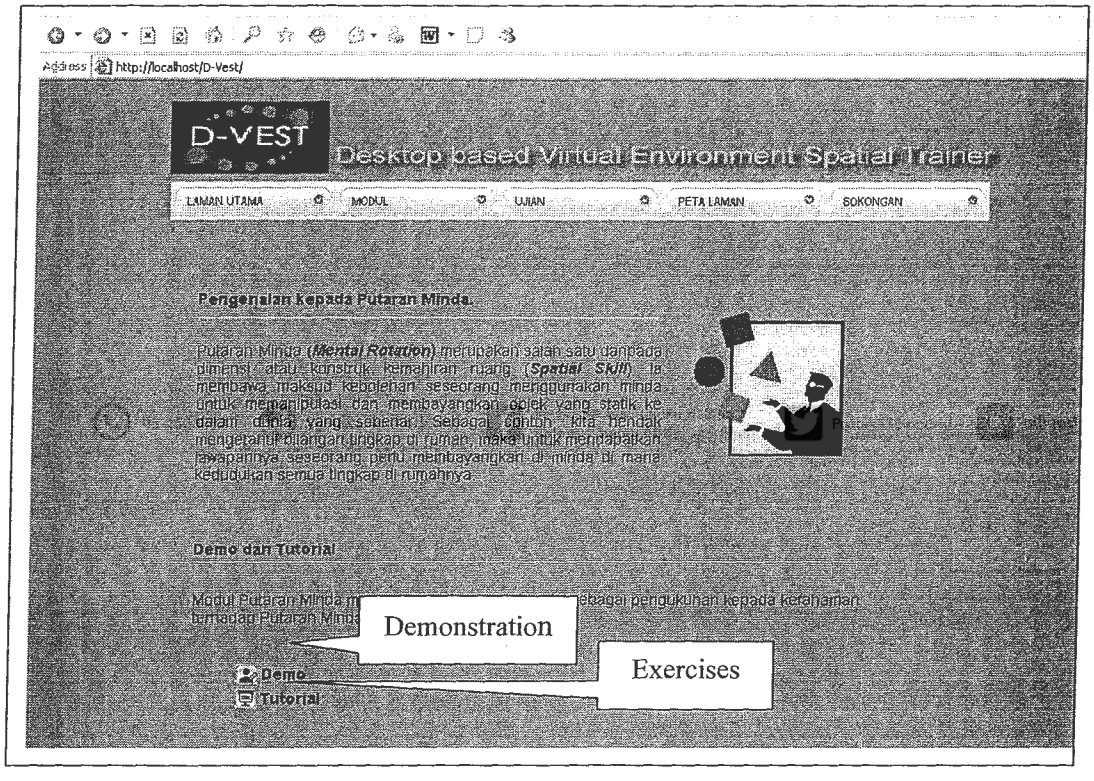



*Figure 4.3.* Mental rotation page depicting brief introduction and hyperlinks.

In the demonstration page, the participants were presented with three levels of demonstration for the three categories of spatial exercises organized as simple, moderate, and complex tasks. The design of this page contains three frames namely the


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drop-down menu, selection for level of demonstration, and display of the virtual environment containing the virtual objects as illustrated in Figure 4.4. The frame used for the display of the desktop VE is maximized to cater for the display of VRML client interface.

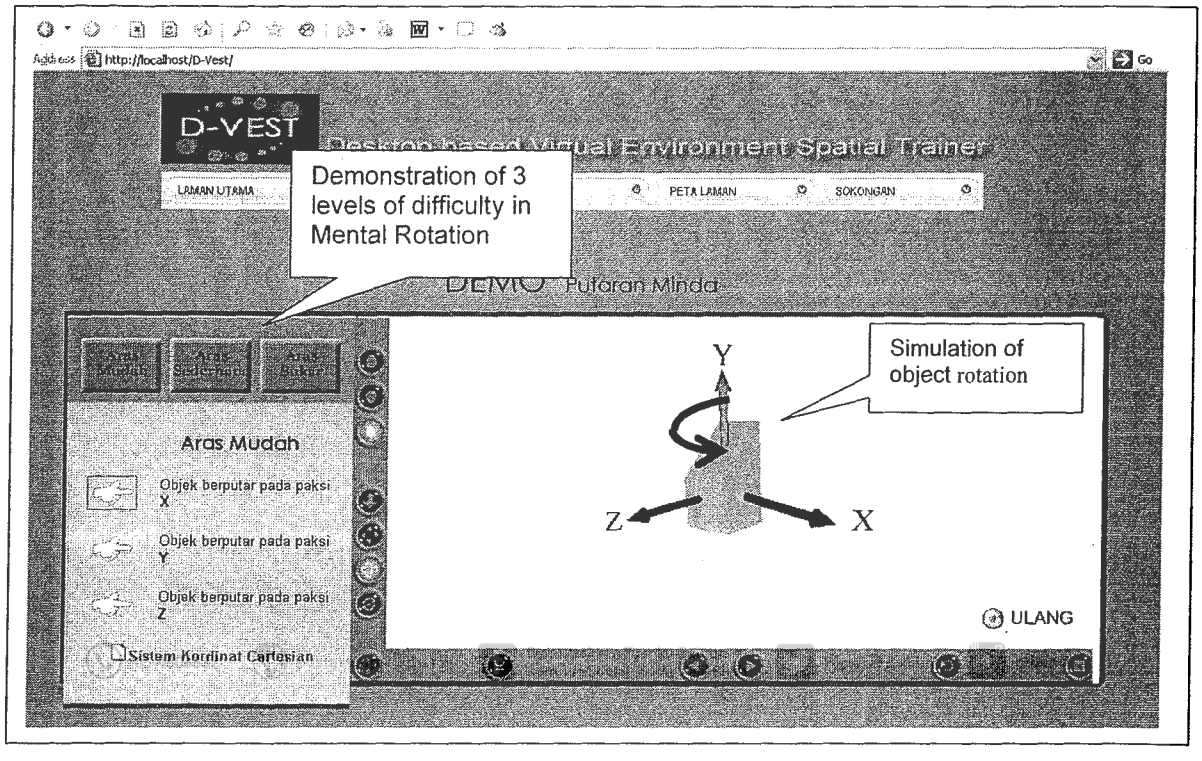



*Figure 4.4.* Demonstration page for mental rotation training.

To begin the spatial execises or tasks, the participants could proceed to the tutorial page, which contains a series of questions with multiple choices to select for the appropriate solutions by clicking the tutorial hyperlink (see Figure 4.5 overleaf). Three frames are used to display the relevant information and objects. The top frame is used to display the title and item number for the questions, the middle frame for depicting the desktop VE, and the lower frame for showing the questions, six choices of solution, selection buttons. In essence, this configuration was so designed to achieve the *spatial*


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*contiguity effect* that allows participants to learn more effectively as words and pictures are presented near rather than dispersed incongruously (Mayer, 2003). The tutorial page containing the spatial exercises that tap on mental rotation is illustrated in Figure 4.5 below.

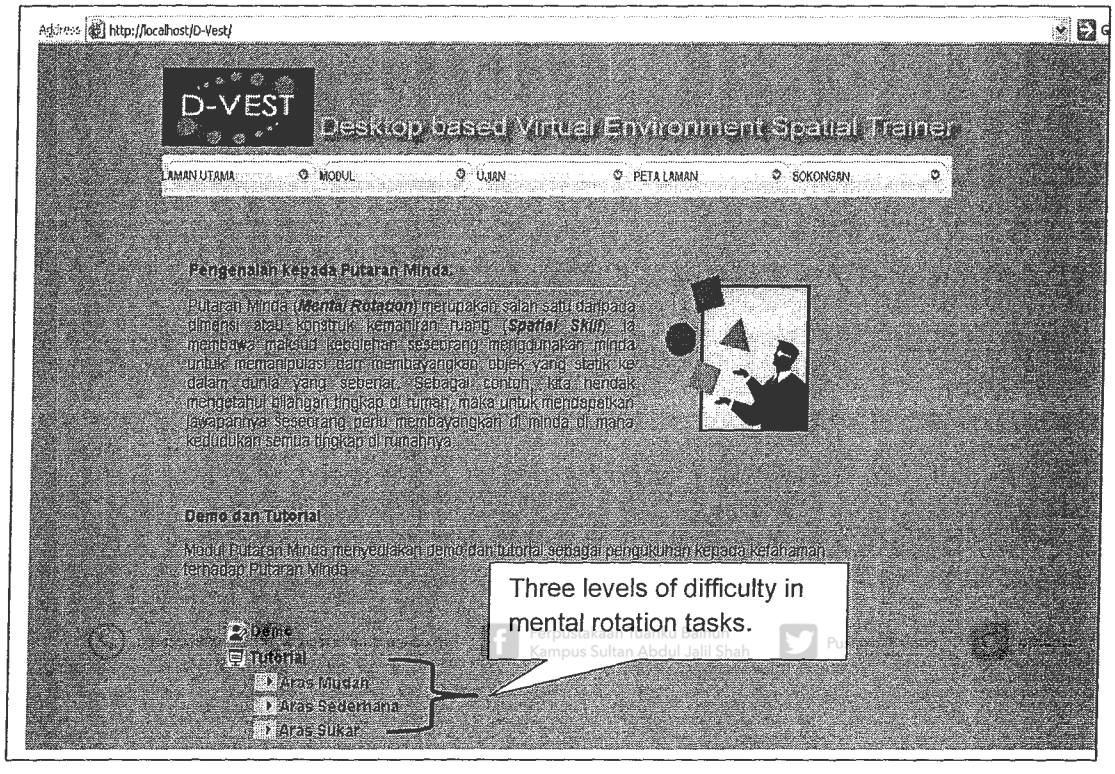



*Figure 4.5.* Tutorial page for Mental Rotation spatial training.

This tutorial page presents a brief introduction of the spatial construct and the importance of this ability. This page also provides a link that demonstrates the concept of the spatial construct and another link for spatial training in the form of spatial exercises designed and presented by its degree of difficulty: simple, moderate, and complex problems as illustrated in Figure 4.5.



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## 4.5 The Development of Virtual Training Objects and Instructional Activities for the Spatial Exercises.

All training objects are computer generated by means of 3D description using VRML modeling language. Three-dimensional (3D) models could be developed by using basic primitives as building blocks using VRML but complex shapes are efficiently modeled using either the VRML authoring tools or CAD software equipped with post-processor to convert CAD geometries into VRML format entities. This research undertook the latter approach utilizing an existing CAD software namely AutoDesk's AutoCAD 2008. Geometrical objects were developed in this application and later post-processed into VRML format file describing the 3D geometries through Xanadu's VRML Translator. Effectively, this translator application allows the export of any 3D solid from AutoCAD to VRML format.

Interactive 3D simulations provide more dynamic and appealing representations that can help learners better understand complex phenomena, behaviors and problems. Dynamics behaviour such as animation or simulation of virtual objects can be programmed either by hard coding in the VRML file or using a third party software specially developed to ease the creation of such interactive behaviors. Animations embedded in the spatial trainer were created through the use of the Paraller Graphics' Internet Scene Assembler (ISA). The ISA authoring tool allows the creation of interactive and dynamic 3D applications by reusing existing 3D models that have originated from AutoCAD and other modeling software that support the export to the VRML format. Once the CAD objects are imported into the authoring application the 3D scene or the virtual environment is prepared for use by selecting proper lights and viewpoints for intended display.

Each object in the scene could be programmed with a range of features such as motion, rotation, and collision allowing the creation of complex object behaviors. Objects could be programmed to react to certain events in the scene and/or to users' actions. All the relationships between various events could be established using the



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routing nodes. Having established the required behaviors of the virtual object in the 3D scene the next stage involves outputing of this environment back to the VRML file format. The approach undertaken in this research is graphically summarized in Figure 4.6 below.

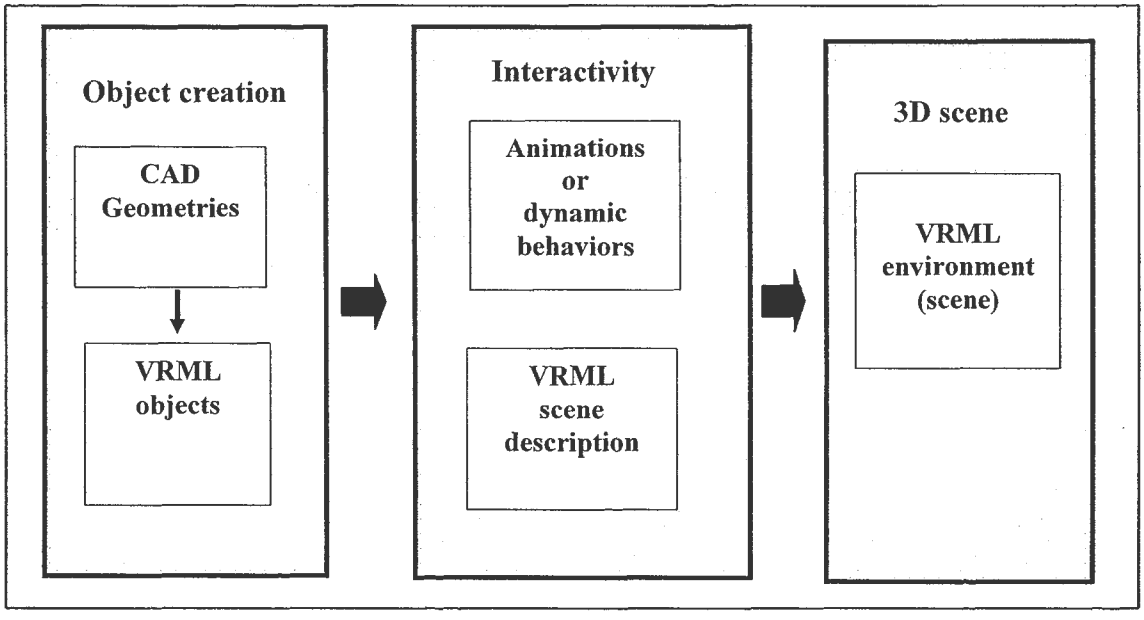



*Figure 4.6.* The creation of a 3D scene through the process of object creation and interaction.

Three types of virtual objects were modeled using the above approach namely the objects for mental rotation consisting of novel shapes, objects for spatial visualization comprising regular blocks in stack arrangement, and the 3D-coordinate icon as depicted in Figure 4.7 and Figure 4.8, respectively on the following page. The mental rotation objects are primarily based on prismatic and rotational shapes (see Figure 4.7). The spatial visualization objects are esentially made of regular rectangular blocks closely arranged and packed as a pile or a stack (see Figure 4.8).

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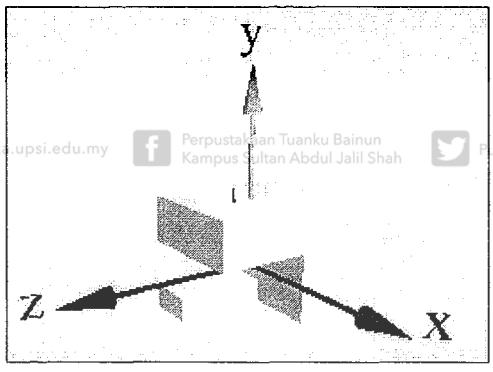



*Figure 4.7.* Types of virtual objects used for mental rotation, and 3D-coordinate icon.

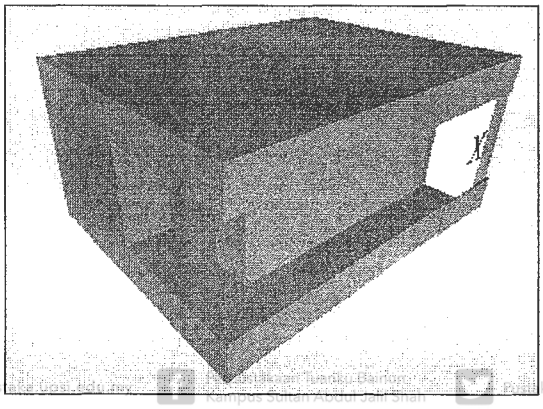


*Figure 4.8.* Types of virtual objects used for spatial visualization.

Instructions were presented to guide the participants to train in spatial visualization and mental rotation as a series of questions requiring mental exercises tapping on these two types of spatial abilities. For example (see Figure 4.9 overleaf), each mental rotation exercise requires a learner to read a question and then choose a particular choice from a set of solutions indicating the accurate rotation(s) of a comparison object (i.e., object on the right side of the figure) to perfectly match a target figure (object on the left side of the figure). The process of choosing a particular choice would enforce the learner to engage in mental rotation in solving this kind of task.



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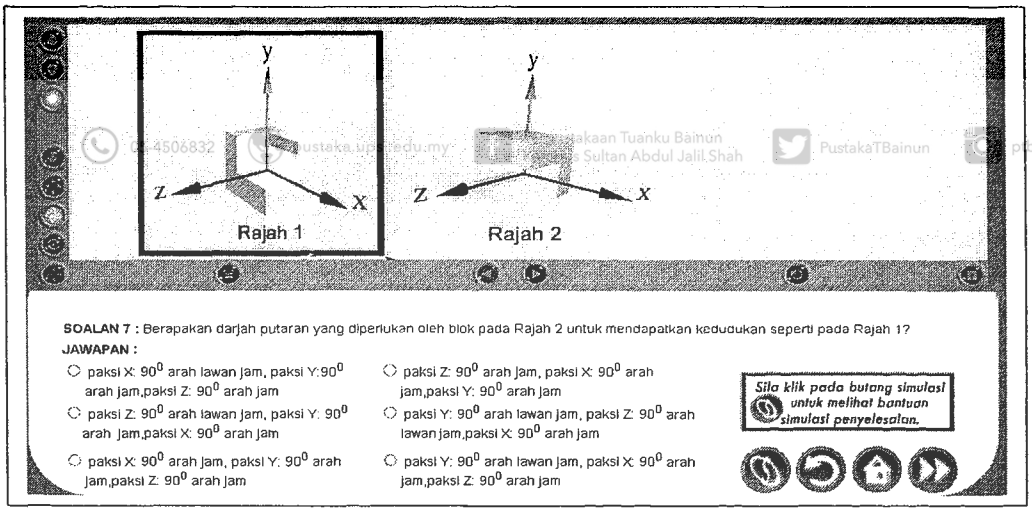



*Figure 4.9.* The mental rotation training page.

As for the spatial visualization exercises, each question entails a learner to read a question and then to decide a particular choice among a set of choices indicating the correct number of blocks that are in contact with a target block as shown in Figure 4.10 below.

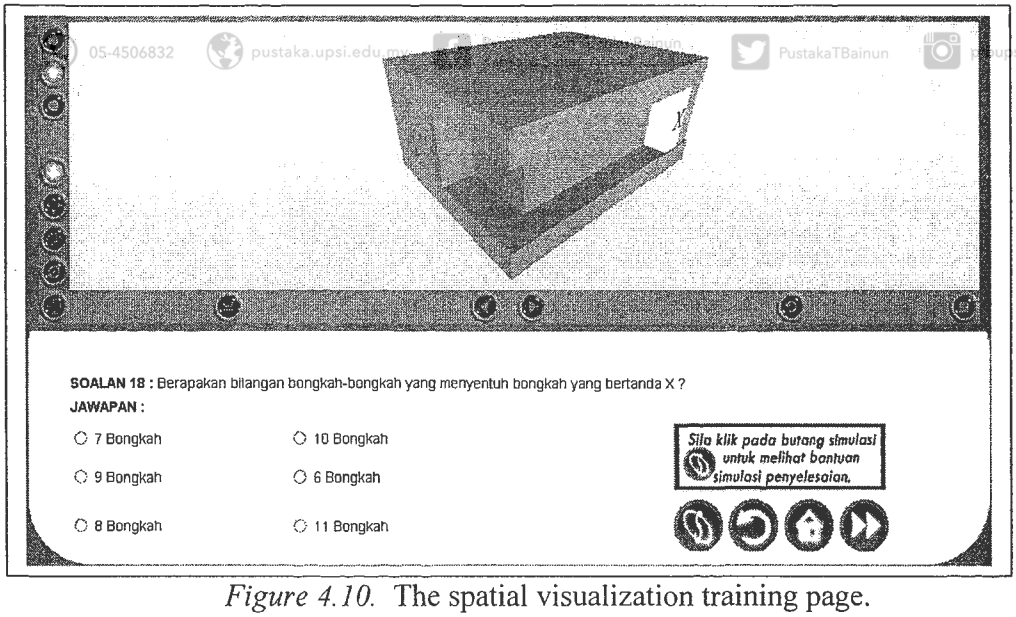



*Figure 4.10.* The spatial visualization training page.



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As shown in Figure 4.10, one of the blocks in a stack is colored distinctly from others and marked 'X'. Determining the exact number of the other blocks that are in contact with this particular block necessitates a learner to visualize the faces of this block and their relations with other neighboring faces belonging to the other blocks. The learner could interact with the scene using the interface in order to get a closer view and/or clearer perspective of the spatial arrangement of the blocks.

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## 4.6 The Instructional Design of the Mental Rotation and Spatial Visualization Tasks.

The participants trained in mental rotation and spatial visualization through solving spatial tasks as a series of spatial exercises that tap on specific mental operations. To build the confidence of the participants to master the exercises had entailed properly designed instructions to guide them through the training process. Instructions and training outcomes had to be made clear, specific, and explicit from the start to allow the participants to formulate the correct mental schema of the spatial tasks being studied. Without these basic requirements, engagement in training might not achieve the desired level and/or commitment in training might not be sustainable over a longer period. The degree of difficulty of the spatial exercises had to be gradually raised from one level during the training phase to the next, intermediate level to ensure that experience and knowledge gained from the previous stage would facilitate training in the later stage. This reinforced training and learning, as some educational theorists believe that teachers could link together responses involving lower-level skills and create a learning "chain" to teach higher-level skills as explained by Roblyer, Edwards, and Havriluk (1997). It is crucial that all the skills needed to lead up to the desired behavior are determined in a systematic (i.e, step-by-step manner) to ensure students can learn effectively ( Higbee, Ginter, & Taylor, 1991).

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This study incorporated the recommendations and best practices advocated by instructional and educational technologists in that the lessons were structured from simple



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concept from the onset of learning, progressing to intermediate level after mastering the previous training contents, and finally immersing training in higher-level thinking. The systematic and orderly progression of training using appropriate instructional materials and training activities ensured training would take place effectively addressing essential elements of cognition, skills or knowledge to be imparted at one level prior to advancing to the next level of training. The instructions and contents of the spatial training exercises had been designed and developed in tandem with the principles explicated above. Three categories of spatial training in mental rotation and spatial visualization had been structured in the spatial trainer based accordingly on the levels of difficulty. The levels of difficulty in these exercises were based on the degree of mental efforts needed in solving the spatial tasks.

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### 4.6.1 Levels of Difficulty in the Mental Rotation Tasks

The variable or factor that determines the degree of difficulty for the mental rotation tasks is based on the number of rotations a learner needs to mentally picture and rotate in his or her mind. The higher the number of rotations the greater is the difficulty when solving the mental rotation tasks. A mental rotation task is conceptualized as low level in terms of difficulty when only a single rotation about an imaginary axis (i.e., either *x, y* or *z*) axis) in the learner's mind is required to solve it. Likewise, spatial tasks of moderate or intermediate level would entail two mental rotations about two imaginary axes (i.e., either *x* and *y, x* and *z,* or *y* and *z* axes) to be carried out during problem solving.

Complex tasks of higher level of difficulty would involve two to three mental rotations of mental images of 3D objects about two or three axes. To make the tasks even more challenging the virtual 3D objects were created using unfamiliar, novel shapes, which would eliminate any advantages that a learner might have if familiar objects were used. The definition of an object in three dimensionality involves *x, y*, and *z* dimensions representing its *width, height*, and *depth* respectively as shown in Figure 4.11 overleaf



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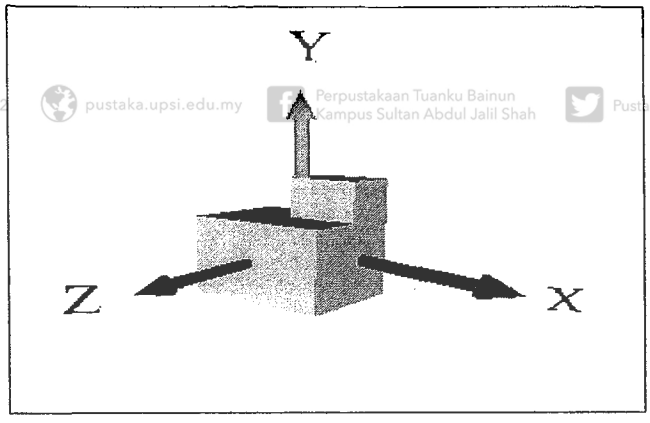



*Figure 4.11.* An object defined in 3D-space using three-coordinate system.

An object could be oriented by rotating along any of the three axes to reach a desired orientation. Tapping mental rotation ability or skill is made possible when two objects are juxtaposed and instructions can be designed in two basic approaches. The first involves determining whether the two objects are congruent or incongruent which will entail visualizing the required rotation(s) of one object to match the other object. On the other hand, the second approach is to ask a learner to find the correct rotation(s) needed to match the two objects. This study employed the second strategy as it is more effective as instructions could be designed to enforce mental rotation operations (i.e., spatial reasoning) in solving the tasks rather than risking students to employ analytical stragegy or they will simply make a guess that will be inevitable if the first approach were chosen.

Figure 4.12 on the next page depicts the first strategy in its simplest form, involving the display of two objects together side by side and a learner is asked to decide whether the two are congruent or incongruent which is based on classical mental rotation test designed by Shepard and Metzler (1974). The target object and comparison object are positioned left and right respectively in the given figure.



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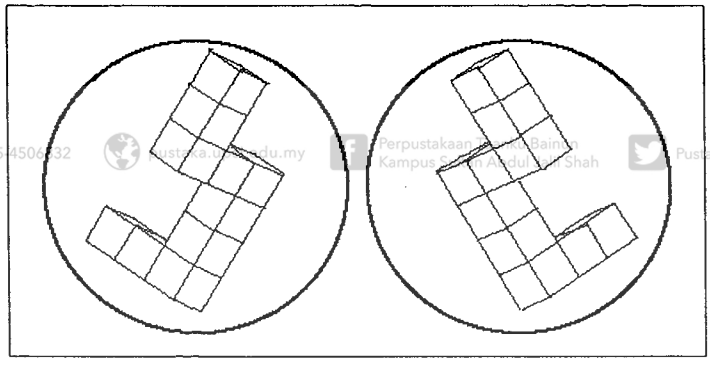


*Figure 4.12.* The classical Shepard and Metzler's mental rotation task.

Solving this task entails a three-stage process: visualizing a comparison object, rotating that object in the appropriate steps, and finally comparing that object with the target object; these operations are executed in sequence. Training based on this approach will not be effective mainly because a learner can resort to guessing to make the comparison of the two objects rather than engaging in mental rotation. The second strategy is more effective in that both the target and comparison objects are congruent and the task involves identifying the appropriate rotations along the corresponding axes to make the latter registers with the former in terms of orientation. Spatial exercises could be designed to present several choices of possible rotations given a pair of congruent objects; one being displaced from the other, as shown in Figure 4.13 below.

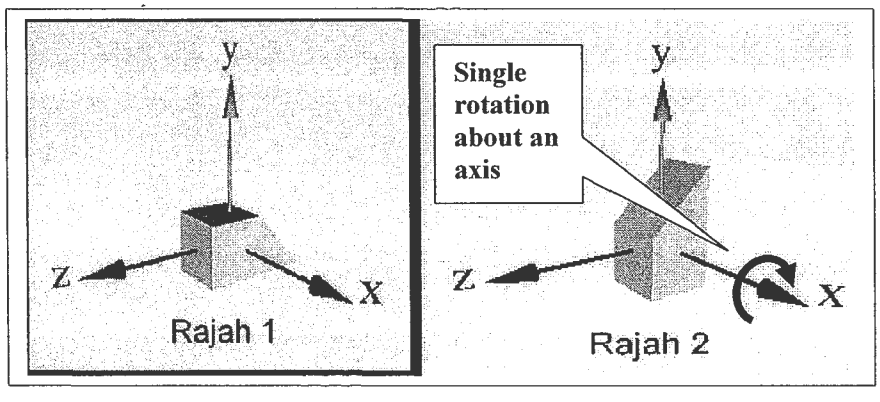



*Figure 4.13.* Rotations of the comparison object to match the orientation of the target object.

The magnitude for each rotation is set at 90 degrees either clockwise or anti-clockwise about the *x*, *y* and *z*-axes to assist better visual perception as smaller angles than this are not easily discerned in the computer-generated environment. As for the basic task as depicted in Figure 4.13, the comparison object (on the right of the figure) needs to be rotated 90 degrees clockwise about the *x* axis to match the orientation of the target object (on the left of the figure). Solving by rotations in 3D space requires a basic understanding of the *Three-Coordinates Cartesian System* that introduces the concept of objects having six degrees of freedom: three translations and three rotations. A *Right Hand Rule* has to be learned to determine the positive and negative directions of rotation; positive rotations are anti-clockwise and negative rotations are clockwise as depicted on the left side of Figure 4.14 below.

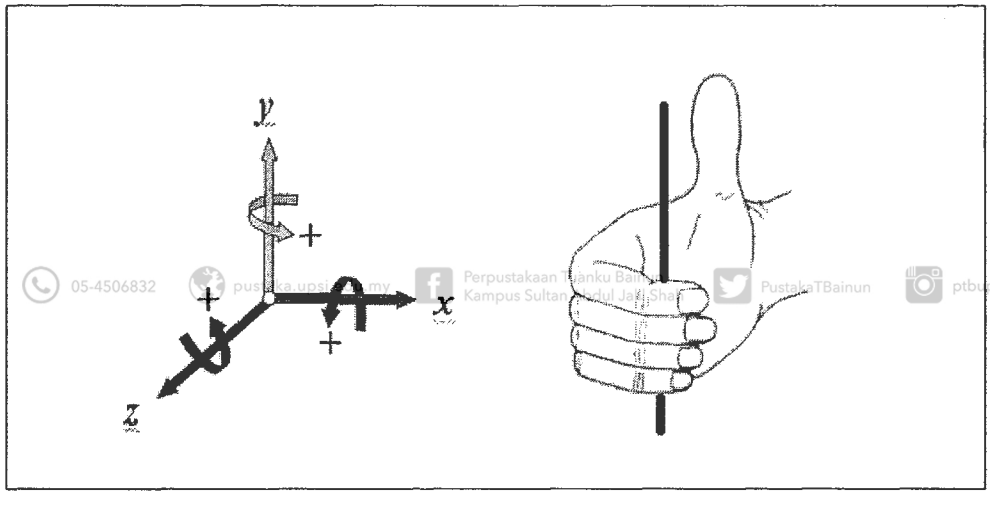



*Figure 4.14.* Positive and negative directions and rotations in 3D space.

Positive direction along an axis is determined by imagining a right hand holding an axis with the thumb pointing to the positive direction. The direction of the other fingers curling the axis is taken as the positive direction as illustrated on the right figure of Figure 4.14.

Mental rotation tasks of moderate level of difficulty involve the rotation of objects about any two axes. The tasks have been designed such that a learner needs to engage in mental rotation involving two steps before arriving at a particular orientation. There is more than one way of achieving this as the order of rotation can be, say rotation about the $x$-axis followed by the $y$-axis, or rotation about the $y$-axis followed by the $x$-axis, to arrive at the final orientation. However, the choices given to the participants only contain one option that represents one of the several correct ways of rotation for the comparison object to match the target object. Figure 4.15 below illustrates a mental rotation task of moderate level of difficulty involving two rotations about two axes, namely $x$ and $y$ axes.

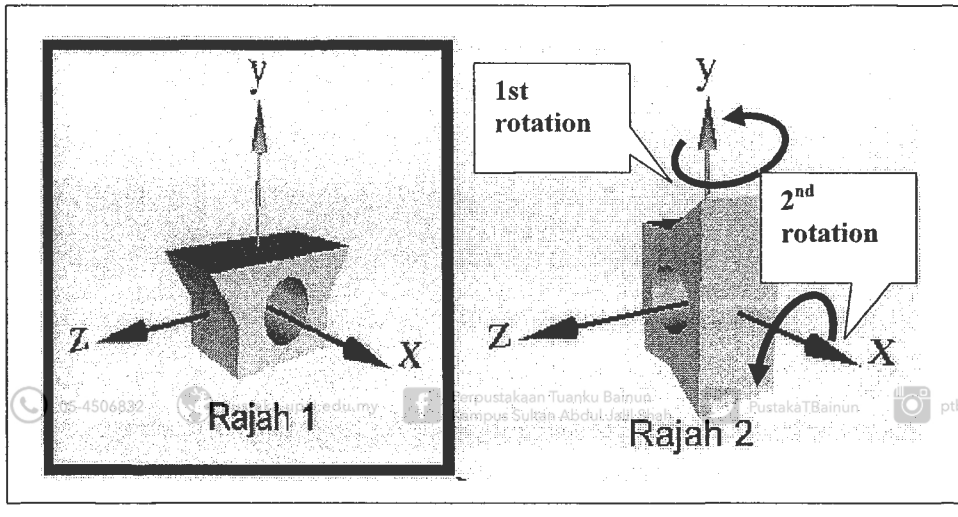



*Figure 4.15.* A moderate mental rotation task.

There will be more than one way of solving this task, however, one of the many possibilities involves rotating the comparison object 90 degrees anti-clockwise about the $y$-axis (see the right figure of Figure 4.15) and then rotating it from that position 90 degrees anti-clockwise about the $x$-axis. This correct method of rotation appears as one of the choices made available to the participant where the remaining choices of rotation will not match the comparison object to the target objects. Other possibilities may involve rotating



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the comparison object 90 degrees anti-clockwise about the *x*-axis followed by 90-degree anti-clockwise rotation about the *z*-axis.

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Mental rotation tasks of high level of difficulty involve rotations of a comparison object about any three axes to arrive at a particular orientation making it congruent with a target object. Like the case for the moderate level, there is more than one way to solve the tasks as the order of the rotations could be performed in more than one way. However, the choices given to the participants contain only one option that represents one of the many possible ways of rotating the comparison object to match the target object. Figure 4.16 below illustrates a mental rotation task of high level of difficulty involving three rotations about three axes of a novel-shaped object.

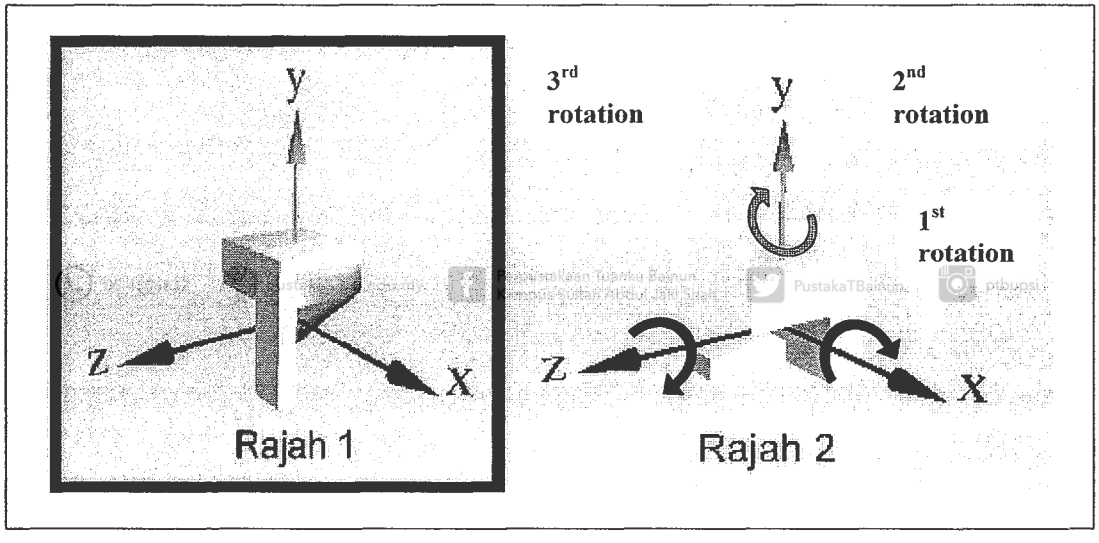



*Figure 4.16.* A complex mental rotation task.

One correct way of solving the task in Figure 4.16 involves rotating the comparison object (i.e., the right figure) 90 degrees clockwise about the *x*-axis, followed by rotating it 90-degree clockwise about the *y*-axis, and finally rotating it 90 degrees clockwise about the *z*-axis.


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### 4.6.2 Levels of Difficulty of the Spatial Visualization Tasks

The variable that determines the degree of difficulty for the spatial visualization tasks is based on the number of blocks in contact with a target block in a stack arrangement entailing a learner to mentally visualize and count them his or her mind. The higher the number of blocks used, the greater is the difficulty in solving the spatial visualization tasks. A simple task of low-level difficulty is based on a few blocks making contact with a target block. A moderate spatial visualization task involves more blocks that are in contact with a target block in a stack arrangement. A complex task of high-level difficulty in spatial visualization involves greater number of blocks touching the target block in a stack of complex configuration. In addition to using more blocks in the stack, the tasks could also be made more challenging by having gaps or voids in the stack arrangement. The modeling of gaps in the stack involves removing one or two blocks from the regular arrangement of the stack making it harder to discern the spatial arrangement. Figure 4.17 below shows a spatial visualization exercise of low-level difficulty where one needs to visualize the spatial arrangement consisting of regular blocks making contact with the target block in her or his mind.

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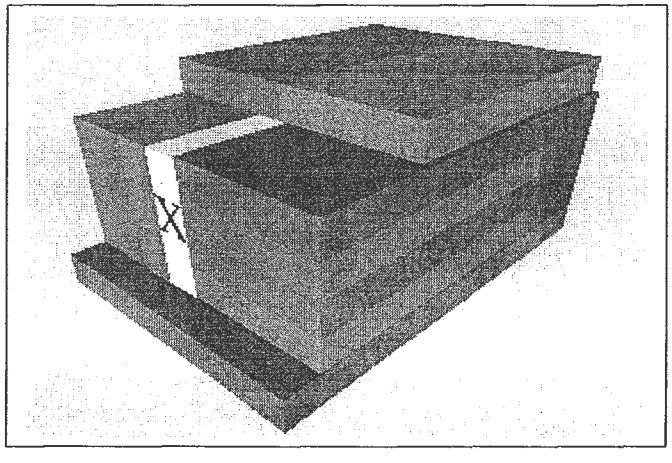


*Figure 4.17.* A simple spatial visualization task.



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For example, the target block marked 'X' shown in Figure 4.17 is embedded in a stack and spatial training involves imagining or visualizing the faces of the other adjacent blocks making contact with it. As for this case, ten (10) blocks are in contact with the target block marked 'X'.

For tasks of moderate level of difficulty, more virtual blocks were used to create denser configuration and/or some gaps were also introduced making visualization harder than the previous level. Figure 4.18 shown below shows a spatial arrangement of blocks where there are eight (8) blocks – by counting their faces – making contact with the target block marked 'X'. In addition, a distinctive color (in this case using shaded yellow) is used to provide better discrimination of the target block from the other blocks.

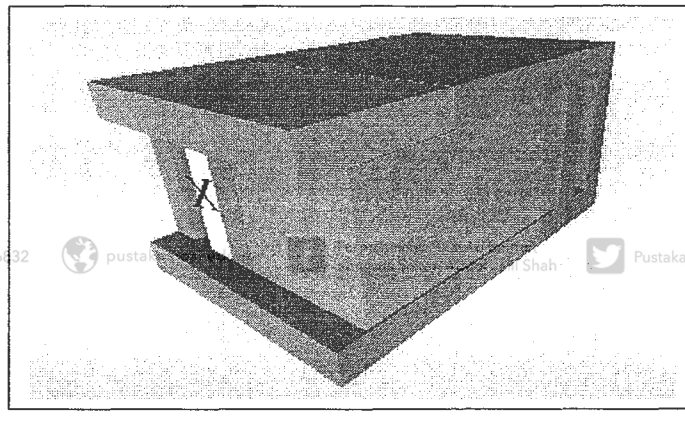



*Figure 4.18.* A moderate spatial visualization task.

For a complex task of high-level difficulty, a greater number of virtual blocks were used, and some gaps were introduced making visualization harder than the moderate level. In addition, the complexity of the task was raised by having intricate arrangement of blocks. The use of high number of blocks, several voids, and intricate configuration of the stack introduced tasks that were more challenging to the participants in this study. Figures 4.19 on the following page shows a spatial arrangement of blocks where there are eleven (11) blocks - by counting their faces -

making contact with the target block marked 'X' which is highlighted with a distinctive color (in this case using shaded yellow) providing better discrimination of the target block from the others.

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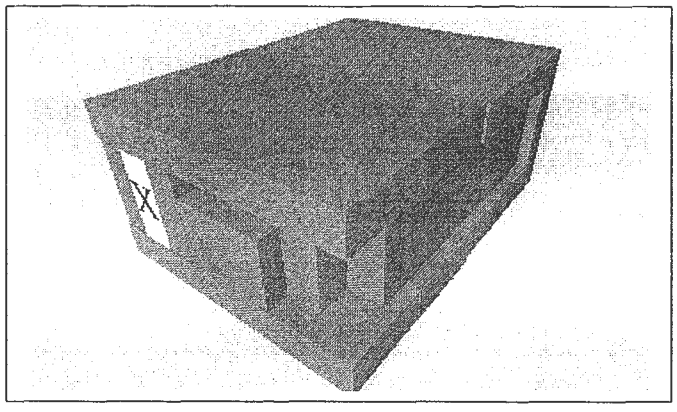



*Figure 4.19.* A complex spatial visualization task.

Figure 4.20 below summarizes the levels of the spatial training: simple, moderate, and complex, which were used in the spatial trainer (DVEST) comprising demonstrations and spatial ability exercises.

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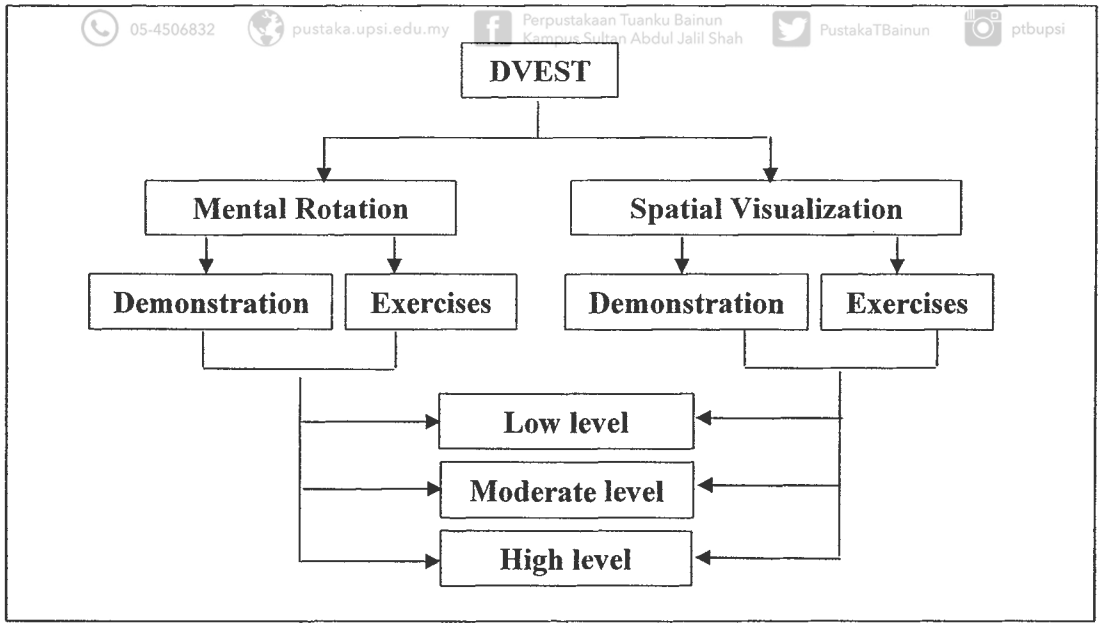



*Figure 4.20.* Levels of spatial training in the spatial trainer.



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As noted earlier, a feedback technique is an important feature in the constructivist-based training or learning activities that allows learners to immediately receive a message for each attempt they have made. This feedback technique will inform learners the correctness or incorrectness to each response that they made when choosing a particular choice (i.e., solution) among the multiple choices in the spatial exercises. The use of such a feature follows the suggestions of earlier researchers that emphasize feedback technique as an efficient methodological strategy that affects future performance of spatial task, in particular mental rotation, by decreasing the number of errors and the reation time (Lohman & Nichols,1990; Richardson, 1994). Figure 4.21 below illustrates a feedback in response to an attempt made in a spatial exercise.

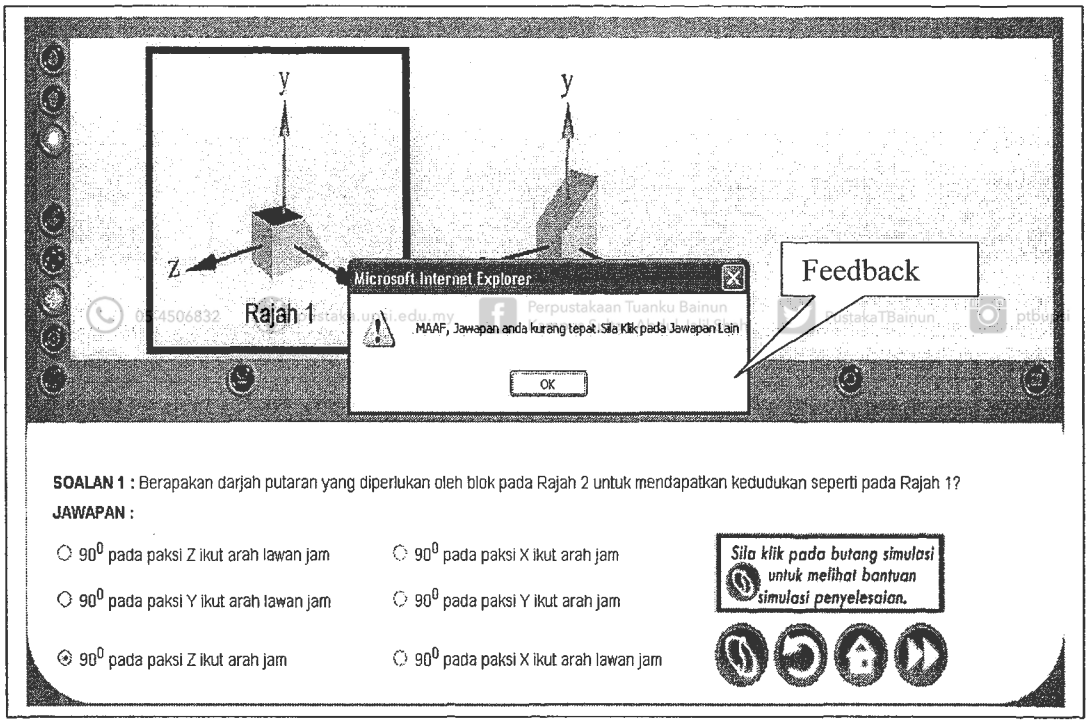



*Figure 4.21.* A feedback informing the status of a response.


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## 4.7 Navigational Attributes of the Spatial Trainer (DVEST)

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Effectively, solving the spatial tasks in DVEST entails an ability to navigate and interact with the virtual objects within the virtual environment or scene in orderly and systematic approach. This entails gathering of new spatial information, retrieving of existing spatial knowledge, and forming an accurate updated cognitive model of the virtual environment in user's mind (Wang, 2004). The synthesis of the above processes engenders configural knowledge enabling an understanding of an interconnection between features or objects in the virtual environment. Effectively, this synthesis facilitates an individual to make inferences between the artifacts and to comprehend their interrelationships in 3D space. Wickens and Prevett (1995) proposed a model to conceptualize the intricate characteristics of navigational tasks into one framework incorporating *global awareness* and *local guidance*.

These two tasks are contrasted in terms of the knowledge states necessary to support them. A three-level model of the navigational tasks is depicted in Figure 4.22 shown overleaf. Local guidance in DVEST is conceived as the task of identifying specific features of object within the virtual environment while global awareness is regarded as an understanding of spatial configuration of various objects in that environment. The knowledge needed to support each of these tasks can be contrasted to the perspective requirement for information displayed from ego referenced and world referenced frames of reference. The fundamental display features for presenting egocentric information include perspective viewing, track-up rotation, and proper alignment between viewing direction and the control axis. Figure 4.22 on the following pages illustrates the nagivational concepts as espoused by Wickens and Prevett (1995).

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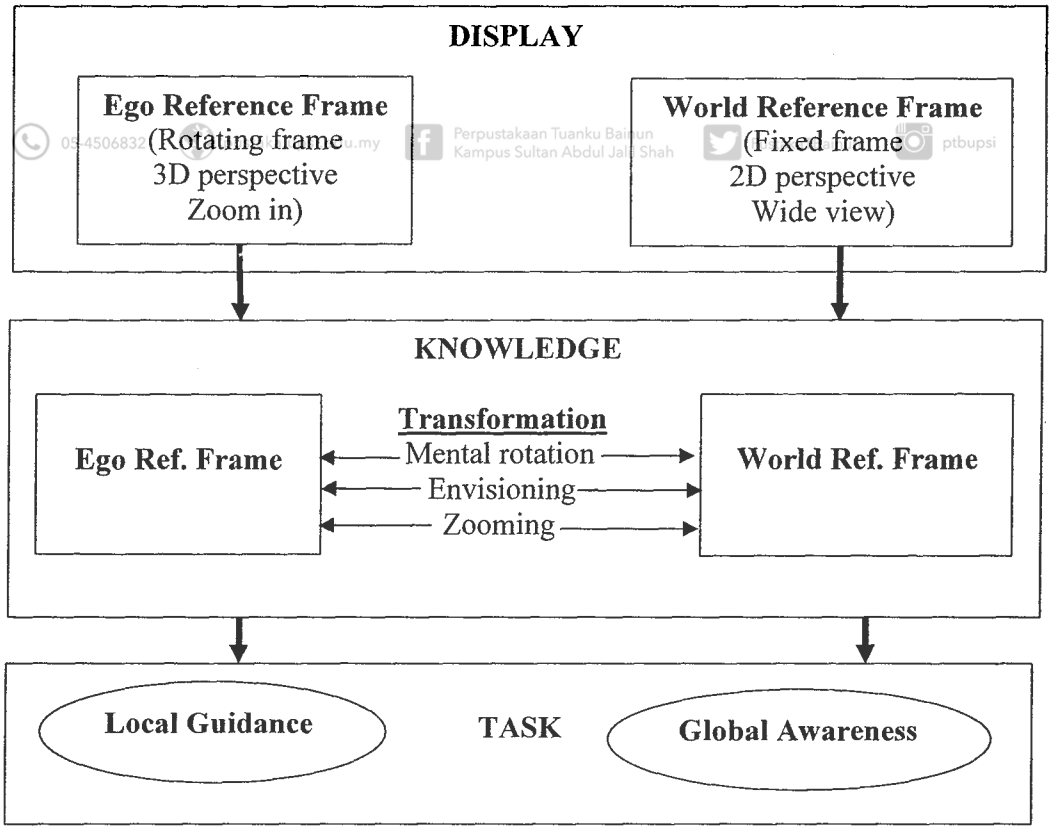


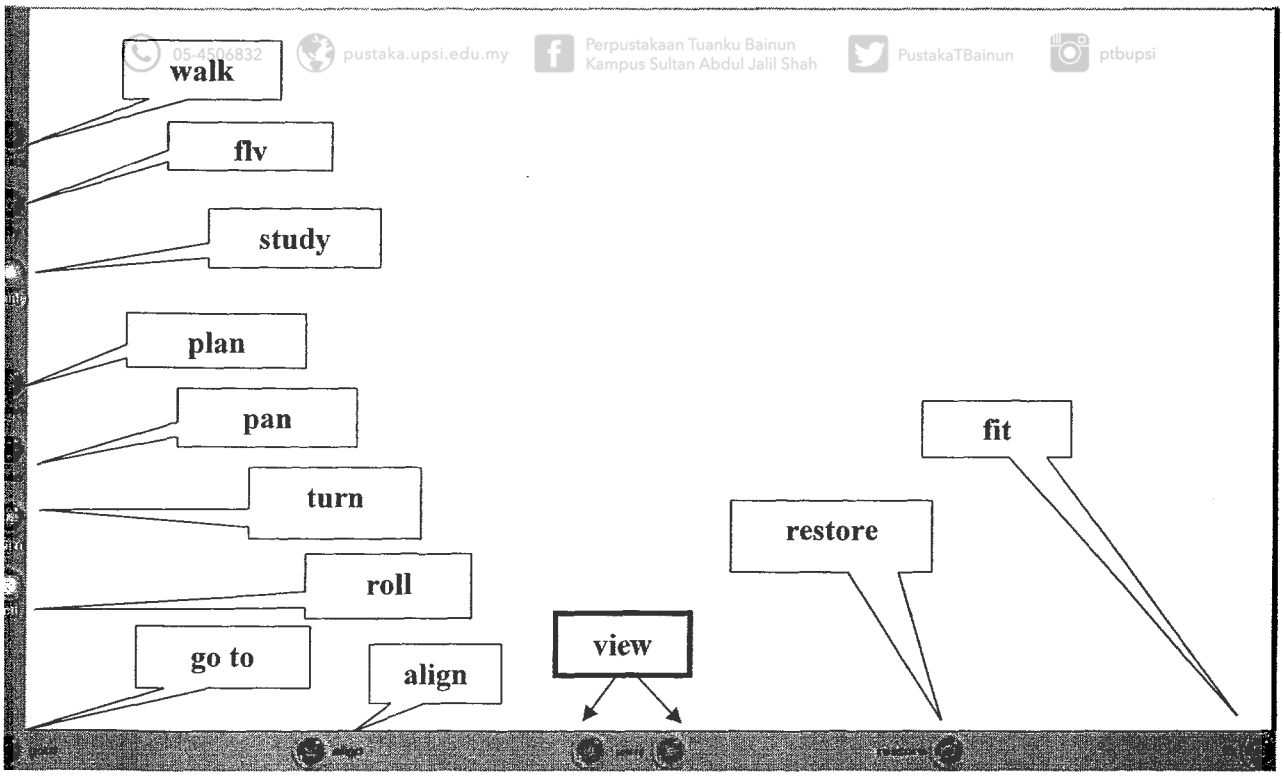

*Figure 4.22.* Navigational Model Adapted from Wickens and Prevetts'.

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Crucial to the global awareness, the knowledge states should be exocentric in nature that are independent of the observer's location and orientation. As depicted in Figure 4.22, such display should provide a capability to represent exocentric characteristics of spatial information by zooming out to a wide viewing angle. Being designed on the desktop platform, navigation in the spatial trainer is achieved through the exocentric approach based on the world reference frame. The interface for navigation in the spatial trainer is based on the Cartona's VRML client as depicted in Figure 4.23 shown overleaf.



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*Figure 4.23.* The mouse-controlled VRML client interface used for navigation via navigation buttons.



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## 4.8 Summary

The development of the spatial trainer in enhancing the participants' spatial ability, namely spatial visualization and mental rotation was based on a conceptual framework informed through the constructivist learning theory and instructional design guidelines. Object creation and interactions for spatial training were modeled and implemented using the virtual reality modeling language (VRML). The training entailed the participants to follow the training activities tapping on mental rotation and spatial visualization. The desktop virtual environment trainer comprised virtual objects in 3D virtual environment. Problem solving by the participants involved enforcing them to follow the instructions and questions, thus ensuring them to remain focused on a problem domain (i.e., exogeneous approach); ensuing navigation and interaction with the virtual objects in the environment helped construct meaningful spatial strategy as they contemplated the correct solutions (i.e., endogeneous approach). Spatial training comprised three levels of problem solving in spatial visualization and mental rotation: starting from simple tasks, then progressing to moderate tasks, and finally completing complex tasks. Feedback mechanism and animations embedded in the training system also provided relevant cognitive tools during problem solving (i.e., dialectic approach), which further enhanced the training effectiveness.

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# CHAPTER 5

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# RESEARCH FINDINGS

## 5.0 Introduction

This chapter reports the findings of the statistical analyses for the survey research and experimental research after the interventional training in spatial visualization (SV), mental rotation accuracy (MRA), and mental rotation speed (MRS). For the survey research, a significant and moderately strong correlation between perceived ability and spatial experience was found especially in high spatial content topics. In general, students reported difficulty in learning high spatial content topics such as *isometric projection, orthographic projection*, and *auxiliary views*. In addition, males tended to regard themselves high in spatial experience compared to their female counterparts. The correlation between perceived ability and previous mathematics achievement was significant but low in strength. Similarly, the correlation between perceived ability and gender was significant but small in strength. Regression analysis attested that spatial experience was the only variable to have a strong predictive power to account for variation in students' perceived ability to learn engineering drawing at the foundational year.

For the experimental research, the results of the *independent t-tests* indicated that all the three groups and both genders were statistically equivalent in all the pretest measures at the outset. *Paired sample t-test* revealed that there were significant main effects of training method and gender, and interaction between these two factors after training in spatial visualization. Improvement gains in SV were higher in interaction-enabled method, moderate in animation-enhanced method, and low in conventional method, and in general, boys outperformed girls. Interaction effect was observed to be



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significant where boys trained better in the novel two methods but trained poorly in the conventional method. Girls did not show any differential improvement gains based on the training methods that they received.

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For mental rotation accuracy, improvement gains were equivalent in interaction-enabled and animation-enhanced methods, and boys were more accurate than girls were. Interaction effect was significant indicating that girls improved irrespective of the training methods that they used, but on the other hand, boys tended to train better in the novel methods. No significant improvement gain in mental rotation speed in the experiment was observed. Finally, those trained in interaction-enabled method outperformed the other groups in basic engineering drawing task that was attributed to their higher spatial ability. Spatial visualization was found to be the critical factor that explained the variance of the performance in basic engineering drawing task inferring that cognitive process evoked during training and solving the spatial task shared similar mental process that facilitated the training transfer.

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## 5.1 Findings of the Survey Research

The rating of perceived ability of students to learn each unit of the engineering drawing course at the foundation year is illustrated in Table 5.1 (shown overleaf) in descending order. The higher the reported average rating by the respondents, the easier they perceived their ability in learning a particular topic. On the other hand, a lower reported average rating implies greater difficulty in learning a specific topic. The topic reported to be easy to learn was the *Introduction to engineering drawing,* having an average rating of 4.91 as illustrated in Table 5.1 (shown overleaf). On the other hand, the topic *Auxiliary views* was rated to be the most difficult unit to learn as reported by the respondents in the survey.



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Table 5.1
*Rating of perceived ability to learn the topics of engineering drawing*

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| Topics: | Average rating: | Spatial categorization: |
|---|---|---|
| Introduction to Engineering Drawing | 4.91 | low |
| Lines and Lettering | 4.43 | low |
| Sketching | 2.73 | moderate |
| Geometrical construction | 2.51 | moderate |
| Oblique views | 2.32 | moderate |
| Isometric drawing | 2.24 | high |
| Orthographic drawing | 2.02 | high |
| Computer Aided Design (I) | 1.64 | moderate |
| Auxiliary views | 1.62 | high |

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Note: Higher rating implies higher perceived ability to learn the engineering drawing topics.

The different ratings recorded for these two topics (i.e., Introduction to engineering drawing and Auxiliary Views) represent the two poles of the students' perception on their ability to learn the topics of engineering drawing. This is not surprising given the differential spatial contents where the learning of the former is primarily based on factual information, whereas the latter is heavily loaded with spatial contents needing greater use of spatial thinking. Particularly, the finding of lowest perceived ability to learn the Auxiliary Views topic runs parallel with the categorization of spatial content as this topic deals with the projection of views of inclined surfaces from the three principal planes of orthographic views. Understanding of the



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orthographic views would be crucial in learning the auxiliary views. The ratings of perceived ability to learn all the nine topics of engineering drawing at the foundational year are depicted in Table 5.1.

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Interestingly, the topic of *Computer Aided Design (I)* was perceived to be the second highest difficult unit to learn next to learning of *Auxiliary Views* topic. It is plausible that the low perceived ability to learn was partly attributed to students having to work with CAD software, which requires familiarization with an environment completely different from the realm of the manual drafting practice that they normally encountered. This particular topic is concerned with the practice of two-dimensional drafting using AutoCAD 2008 requiring students to learn basic commands and functions to produce engineering drawings composed of 2D geometrical entities. Three-dimensional solid modeling is covered in Computer Aided Design (II) topic in the following year. Other topics that had been categorized as highly spatial, namely *Orthographic drawing,* and *Isometric drawing* were perceived to be relatively difficult as expected. These two topics are very important as they constitute the basis of an engineering drawing according to Bertoline and Wiebe (2002), and Olkun (2003) where skills in understanding and production of engineering drawing are deemed critical by many practitioners and educators despite current focus on computer-aided design based on 3D modeling over manual drafting practice as cautioned by Barr (2004).

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Table 5.2 shown overleaf summarizes the *Pearson correlation* scores on perceived ability to learn the four levels of engineering drawing topics based on gender, spatial experience, and previous mathematics achievement of the respondents in the survey research.



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Table 5.2

*Pearson correlations for perceived ability, spatial experience, previous mathematics achievement, and gender.*

| Measures | Perceived ability to learn: All topics | High spatial topics | Moderate spatial topics | Low spatial topics |
|---|---|---|---|---|
| Spatial experience. | .489** | .367** | .449** | .021 |
| Previous mathematics | .172** | .208** | .277** | .228** |
| achievement. | .456* | .461** | .354** | -.349** |
| Gender. | | | | |

**p<.01, *p<.05

For all topics grouping, the correlation between perceived ability to learn and spatial experience was significant and moderately strong, $r(354) = .49$, $p = .001$. High spatial experience respondents tended to have greater perceived ability to follow the engineering drawing instructions for all topics. A significant but weak correlation was found between perceived ability and previous mathematics achievement, $r(354) = .17$, $p = .001$ where, in general, high mathematics achievers tended to have greater perceived ability to learn all topics in engineering drawing. A significant and moderately strong correlation was found between gender and perceived ability, $r(354) = .46$, $p = .001$, indicating that learning all topics of the subject matter was favorably perceived by males compared to their female counterparts

For the high spatial content category, the correlation between perceived ability and spatial experience was significant and moderately strong, $r(354) = .37$, $p = .001$. This indicates that the ability to learn these topics was relatively higher among those of



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high level of spatial experience than low spatial experience respondents were. Previous mathematics achievement and perceived ability to learn these topics was significantly but lowly correlated, $r(354) = .21$, $p = .001$. The correlation between perceived ability to learn these topics and gender was significant and moderately strong, $r(354) = .46$, $p = .009$. Generally, males tended to view learning of these topics of high spatial contents namely, isometric drawing, orthographic drawing, and auxiliary views to be less problematic compared to females.

Similar pattern of associations was replicated for moderately spatial content topics. A significant and moderately strong correlation was established between perceived ability and spatial experience, $r(354) = .45$, $p = .001$. Those with higher spatial experience tended to have greater perceived ability to learn the topics of sketching, geometrical construction, oblique views, and CAD (I). The correlation between perceived ability to learn these topics and previous mathematics achievement was significant but low in strength, $r(354) = .28$, $p = .001$. A significant but weak correlation was found between perceived ability to learn these topics and gender, $r(354) = .35$, $p = .001$. In general, male respondents tended to regard learning of the topics more favorably than their female counterpart did.

For low spatial content topics, the correlation between perceived ability and spatial experience was very small in strength and not significant, $r(354) = .02$, $p > .05$. All respondents, irrespective of their spatial experience, reported that the learning of the topics of *Introduction to engineering drawing* and *Lines and Lettering* to very easy. A significant but weak correlation was detected between perceived ability to learn these topics and previous mathematics achievement, $r(354) = .23$, $p = .001$. The correlation of perceived ability to learn these topics and gender was observed to be significant but weak, $r(354) = -.35$, $p = .001$. The negative correlation is an indication that females had greater perceived ability than males in learning topics lacking in spatial contents.



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Interrelations between the predictor variables were also investigated revealing significant but weak correlation between spatial experience and previous mathematics achievement, $r(354) = .28$, $p = .001$, as shown in Table 5.3 below. In general, high mathematics achievers reported to have greater experience in spatial activities than low mathematics achievers. In other words, those respondents who had low mathematical ability tended to have less spatial activities compared to their friends who had high mathematic achievements.

Table 5.3
*Inter-correlations among independent variables*

| Measures | 1 | 2 | 3 |
|---|---|---|---|
| 1. Spatial experience | - | .275** | .278** |
| 2. Previous mathematics achievement | | - | -.301** |
| 3. Gender | | | - |

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A significant but weak correlation was found between spatial experience and gender, $r(354) = .28$, $p = .001$. Generally, males tended to report higher experience in spatial activities than females. Negative correlation between previous mathematics achievement and gender was established to be significant but weak in strength, $r(354) = -.30$, $p = .001$. Apparently, female respondents reported higher mathematics achievements compared to their male counterparts in this study.

Multiple regressions employing three predictor variables were conducted and the results are summarized in the following tables. The analysis of the multiple regression for the statistical model employing the scores on perceived ability to learn all



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topics of engineering drawing as the criterion variable revealed a reasonable fit ($R^2$ = 38.8%) and the overall relationship was significant ($F_{3,351} = 74.32$, $p<.001$) as depicted in Table 5.4 below.

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Table 5.4
*ANOVA for spatial experience, mathematics achievement, and gender regressed on all topics of engineering drawing scores.*

| Source | SS | df | MS | F | *p*-value | $R^2$ |
|---|---|---|---|---|---|---|
| Regression | 108.764 | 3 | 36.255 | 74.316 | .000 | .388 |
| Residual | 171.233 | 351 | .488 | | | |
| Total | 279.997 | 354 | | | | |

From Table 5.5 shown below, with other variables held constant, the scores on perceived ability to learn all topics of engineering drawing were positively related to spatial experience factor, previous mathematics achievement, and gender. Male students tended to have higher scores than their female counterparts on the perceived ability to learn all topics as qualified by the simple main effect, which was very significant ($t_{351} = 9.21, p < .001$).

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Table 5.5
*Regression analysis coefficient for model employing all topics of engineering drawing*

| | Non-standardized coefficients | | Standard coefficients | *t* | *p*-value |
|---|---|---|---|---|---|
| | B | Std. Error | | | |
| Constant | .251 | .213 | | 1.177 | .240 |
| Gender | .853 | .093 | .436 | 9.208 | .000** |
| Previous mathematics achievement | .374 | .085 | .209 | 4.382 | .000** |
| Spatial experience | .075 | .011 | .315 | 6.684 | .000** |

** *p<.001*



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The simple main effect attributed to previous mathematics achievement was also significant ($t_{351} = 4.38$, $p < .001$) where high mathematics achievers perceived the learning of all topics more positively than low mathematic achievers. Respondents with high spatial experience rated learning of all topics favorably than those with relatively lower experience in spatial activities ($t_{351} = 6.68$, $p < .001$) as depicted in Table 5.5. Subsequent examination using multiple regression based on stepwise procedure confirmed that gender, spatial experience, and previous mathematics achievement were statistically significant in explaining the variation in the perceived ability to learn all topics of engineering drawing.

The second regression analysis involved a statistical model employing the perceived ability to learn topics of high spatial content as the criterion variable. The analysis revealed a reasonable fit ($R^2 = 35.0\%$) with significant overall relationship ($F_{3,351} = 62.92$, $p<.001$) as shown in Table 5.6 below.

Table 5.6
*ANOVA spatial experience, mathematics achievement, and gender regressed on high spatial content topic*

| Source | SS | df | MS | F | p-value | $R^2$ |
|---|---|---|---|---|---|---|
| Regression | 102.997 | 3 | 34.332 | 62.919 | .000 | .350 |
| Residual | 191.527 | 351 | .546 | | | |
| Total | 294.524 | 354 | | | | |

From Table 5.7 shown on the following page, with other variables held constant, the scores on perceived ability to learn high spatial topics of engineering drawing were positively related to gender, previous mathematics achievement, and spatial experience factor. Male students tended to have higher scores than their female counterparts on the



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perceived ability to learn these topics as qualified by the significant main effect ($t_{351}$ = 10.10, $p < .001$).

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Table 5.7

*Regression analysis coefficient for model employing high spatial content topics*

| | Non-standardized coefficients | | Standard coefficients | t | p-value |
|---|---|---|---|---|---|
| | B | Std. Error | | | |
| Constant | .214 | .226 | | .946 | .345 |
| Gender | .990 | .098 | .493 | 10.099 | .000** |
| Previous mathematics achievement. | .624 | .090 | .340 | 6.908 | .000** |
| Spatial experience | .037 | .012 | .152 | 3.116 | .002* |

*$p<.005$, **$p<.001$

The third statistical model for the regression analysis employs the scores on perceived ability to learn moderate spatial content topics of engineering drawing demonstrated a reasonable fit ($R^2$ = 34.6%) with a significant overall relationship ($F_{3,351}$ = 62.01, $p$ <.001) as illustrated in Table 5.8 below.

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Table 5.8

*ANOVA for spatial experience, mathematics achievement, and gender regressed on moderate spatial content topics*

| Source | SS | df | MS | F | p-value | $R^2$ |
|---|---|---|---|---|---|---|
| Regression | 104.555 | 3 | 34.852 | 62.013 | .000 | .346 |
| Residual | 197.264 | 351 | .562 | | | |
| Total | 301.820 | 354 | | | | |



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The scores on perceived ability to learn topics involving *Sketching*, *Geometrical construction, Oblique drawings,* and *CAD (I)* were positively related to gender, previous mathematics achievement, and spatial experience factors. Male students tended to have higher scores than their female counterparts on the perceived ability to learn these topics as qualified by the significant gender main effect ($t_{351} = 7.40$, $p < .001$). Simple main effect attributed to previous mathematics achievement was also significant ($t_{351} = 6.53$, $p < .001$).

High mathematics achievers perceived the learning of topics of moderate spatial content more positively than the low mathematics achievers. Respondents with high spatial experience rated favorably on learning these topics than those with relatively lower experience in spatial activities as attested by the significant simple main effect ($t_{351} = 5.70$, $p < .001$). Table 5.9 shown below summarizes the findings of the simple main effects of the predictor variables.

Table 5.9
*Regression analysis coefficient for model employing moderate spatial content topics*

| | Non-standardized coefficients | | Standard coefficients | *t* | p-value |
|---|---|---|---|---|---|
| | B | Std. Error | | | |
| Constant | -.200 | .229 | | -.875 | .382 |
| Gender | .736 | .099 | .362 | 7.403 | .000** |
| Previous mathematics achievement. | .598 | .092 | .322 | 6.528 | .000** |
| Spatial experience | .069 | .012 | .278 | 5.703 | .000** |

** $p<.001$

A follow–up procedure using stepwise multiple regression confirmed the above findings where the effects attributed to gender, previous mathematics achievement and spatial experience factors in explaining the variation in the perceived ability to learn

these topics were detected to be significant. Statistical model employing the scores on perceived ability to learn engineering drawing topics of low spatial content as the criterion variable was analyzed by multiple regression revealing a poor fit ($R^2$ = 14.1%), but the overall relationship was significant ($F_{3,351}$ = 19.24, $p$ <.001) as shown in Table 5.10 on below.

Table 5.10
*ANOVA for spatial experience, mathematics achievement, and gender regressed on low spatial content topics*

| Source | SS | df | MS | F | p-value | $R^2$ |
|---|---|---|---|---|---|---|
| Regression | 11.172 | 3 | 3.724 | 19.239 | .000 | .141 |
| Residual | 67.938 | 351 | .194 | | | |
| Total | 79.110 | 354 | | | | |

The scores on perceived ability to learn these topics of engineering drawing comprising low spatial contents such as Introduction to engineering drawing and Lines and Lettering were positively related to previous mathematics achievement and spatial experience factor but negatively related to gender as summarized in Table 5.11 below.

Table 5.11
*Regression analysis coefficient for model employing low spatial content topics.*

| | Non-standardized coefficients | | Standard coefficients | *t* | *p*-value |
|---|---|---|---|---|---|
| | B | Std. Error | | | |
| Constant | 4.703 | .134 | | 34.983 | .000 |
| Gender | -.345 | .058 | -.331 | -.5.903 | .000** |
| Previous mathematics achievement | .106 | .054 | .111 | 1.965 | .050 |
| Spatial experience | .008 | .007 | .061 | 1.084 | .279 |

** *p*<.001



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Interestingly, female students tended to have higher scores than their male counterparts on the perceived ability to learn these topics which was found to be substantial as qualified by the significant simple main effect of gender ($t_{351}$ = -5.90, $p$ < .001). High mathematics achievers perceived the learning of topics of low spatial content more positively than low mathematics achievers. However, the simple main effect attributed to this factor was marginally significant, ($t_{351}$ = 1.97, $p$ = .05). In addition, the simple main effect due to spatial experience factor did not produce significant main effect for this topic of learning ($t_{351}$ = 1.08, $p$ >.05). The stepwise multiple regression analysis was not conducted in view of the poor fit of regression for this fourth statistical model.

## 5.2 Pre-Testing Measures of Spatial Visualization and Mental Rotation Abilities in the Experimental Research

Prior to spatial training, participants' levels of spatial visualization (SV), mental rotation accuracy (MRA), and mental rotation speed (MRS) were measured using the appropriate spatial measurement instruments. The scoring procedures for SV and MRA are based on the number of correct responses out of 32 and 30 respectively. The MRS scoring is based on the reaction time recorded in seconds. The mean scores of the SV, MRA, and MRS pretests for girls ($n$ = 36) were 14.31, 19.17 and 112.28 seconds respectively. Boys ($n$ = 62) attained mean scores of 14.40, 19.56 and 111.51 seconds in the same pretests of SV, MRA, and MRS respectively as summarized in Table 5.12 shown on the following page.



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Table 5.12

*Means and standard deviations for pretest measures of SV, MRA and MRS by gender.*

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| Measures of spatial abilities | Gender | | | | | |
|---|---|---|---|---|---|---|
| | Girls | | | Boys | | |
| | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* |
| Spatial visualization | 36 | 14.31 | 4.47 | 62 | 14.40 | 4.64 |
| Mental rotation accuracy | 36 | 19.17 | 2.44 | 62 | 19.56 | 1.92 |
| Mental rotation speed | 36 | 112.28 | 21.41 | 62 | 111.51 | 28.87 |

Differences attributed to gender factor in spatial visualization, mental rotation accuracy, and mental rotation speed were investigated prior to the treatments of spatial training. Three *independent samples t-tests* were performed to detect if there were any gender differences among the participants in the study. For the spatial visualization pretest, the difference in mean scores of male and female participants was not statistically significant, $t(96) = -.09$, $p = .93$ Likewise, the difference in mean scores for mental rotation accuracy pretest for both gender was not statistically significant, $t(96) = -.89$, $p = .37$. Again, for the mental rotation pretest for reaction time or speed, the difference in mean scores of male and female participants was not statistically significant, $t(96) = .14$, $p = .89$.

The assumption of equal variances for all groups was tested using *Levene's Test* confirming that the variances of these pretest measures were statistically equivalent. The absence of any significant differences in the spatial ability measures suggests that the participants' spatial abilities in visualization and mental rotation (accuracy and speed) were equivalent prior to training.



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Descriptive statistics and a series of *univariate analysis of variance* (ANOVA) were conducted to detect if there were significant differences among the three groups when the participants were randomly assigned into the three different treatment groups. Prior to using this statistical procedure, the assumptions of ANOVA were tested namely *normality* of sampling distribution and *equal variance* through the use of *Kolmogorov-Smirnov* test and *Levene's* test, respectively. The significance values of the first test were above the significance level of .5 indicating that the sample scores were normally distributed. Similarly, the results of the second test at .5 significance level indicated that the variances of the measures were not significantly different among the experimental and control groups.

The ANOVA procedure performed used the means scores of SV, MRA, and MRS as the dependent variables, and training conditions as the independent variables. Table 5.13 shown below summarizes the descriptive statistics of the three groups for the three measures of spatial abilities.

Table 5.13
*Means and standard deviations for pretest measures of SV, MRA and MRS by training condition*

| Measures of spatial abilities | Training condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | interaction | | | animation | | | control | | |
| | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* |
| Spatial visualization | 33 | 15.91 | 4.94 | 33 | 13.43 | 3.90 | 32 | 13.74 | 4.48 |
| Mental rotation accuracy | 33 | 19.36 | 1.52 | 33 | 20.00 | 2.37 | 32 | 18.88 | 2.30 |
| Mental rotation speed | 33 | 102.88 | 27.98 | 33 | 116.60 | 23.67 | 32 | 116.00 | 25.39 |

For the pretest measure of SV, the 33 participants in the interaction group had a mean of 15.91 (*SD* = 4.94); the 33 participants in the animation group had a mean of



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13.43 (*SD* = 3.90), and the 32 participants in the control group had a mean of 13.74 (SD = 4.48). There were no significant differences between these groups prior to spatial training, $F$ (2,95) = 3.035, p=.06. Table 5.14 shown below summarizes the result of the analysis of variance for SV measure of the three groups.

Table 5.14
*Summary of ANOVA for pretest measure of spatial visualization*

| | Sum of Squares | df | Mean Square | F | Sig |
|---|---|---|---|---|---|
| Between groups | 120.681 | 2 | 60.340 | 3.030 | .06 |
| Within groups | 1891.594 | 95 | 19.912 | | |
| Total | 2012.275 | 97 | | | |

From Table 5.12, the pretest measure of MRA, the 33 participants in the interaction group had a mean of 19.36 (*SD* = 1.52); the 33 participants in the animation training condition had a mean of 20.00 (*SD* = 2.37), and the 32 participants in the control group had a mean of 18.88 (SD = 2.29). There were no significant differences between these groups prior to spatial training, $F$(2,95) = 2.36, p = .10. The result of the analysis of variance for MRA measure for the three groups is presented in Table 5.15 shown below.

Table 5.15
*Summary of ANOVA for pretest measure of Mental Rotation Accuracy*

| | Sum of Squares | df | Mean Square | F | Sig |
|---|---|---|---|---|---|
| Between groups | 20.711 | 2 | 10.355 | 2.358 | .100 |
| Within groups | 417.136 | 95 | 4.391 | | |
| Total | 437.847 | 97 | | | |



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From Table 5.12, the pretest measure of MRS, the 33 participants in the interaction group had an average reaction time of 102.89 (*SD* = 27.98); the 33 participants in the animation group had an average reaction time of 116.60 (*SD* = 23.67), and the 32 participants in the control group had an average reaction time of 116.00 (*SD* = 25.38). There were no significant differences between these groups prior to spatial training, $F(2,95) = 2.98$, p=.06. Table 5.16 shown below summarizes the result of the analysis of variance for MRS measure in the three groups

Table 5.16
*Summary of ANOVA for pretest measure of Mental Rotation Speed*

| | Sum of Squares | df | Mean Square | F | Sig |
|---|---|---|---|---|---|
| Between groups | 3944.204 | 2 | 1972.102 | 2.975 | .056 |
| Within groups | 62979.258 | 95 | 662.940 | | |
| Total | 66923.462 | 97 | | | |

Post hoc analysis was not carried out since there were no group differences. These findings indicated that the three groups, and both female and male participants were statistically equivalent in terms of prior spatial abilities before the commencement of the interventional programs.

## 5.3 Post-testing Measures of Spatial Visualization in the Experimental Research

The same psychometric instruments for the spatial ability measurements were again utilized to measure participants' spatial abilities immediately after the completion of the spatial training. Comparing the mean scores of the spatial visualization before and after spatial training using the *paired t-test* procedure revealed that the 98 participants had an average difference pre-test to post-test spatial visualization scores of 5.26 (*SD* = 4.73).



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The pretest and posttest measures of this ability are summarized in Figure 5.1 shown below. This indicates that spatial training resulted in a highly significant increase in spatial visualization level, $t(97) = 11.00$, $p = .001$.

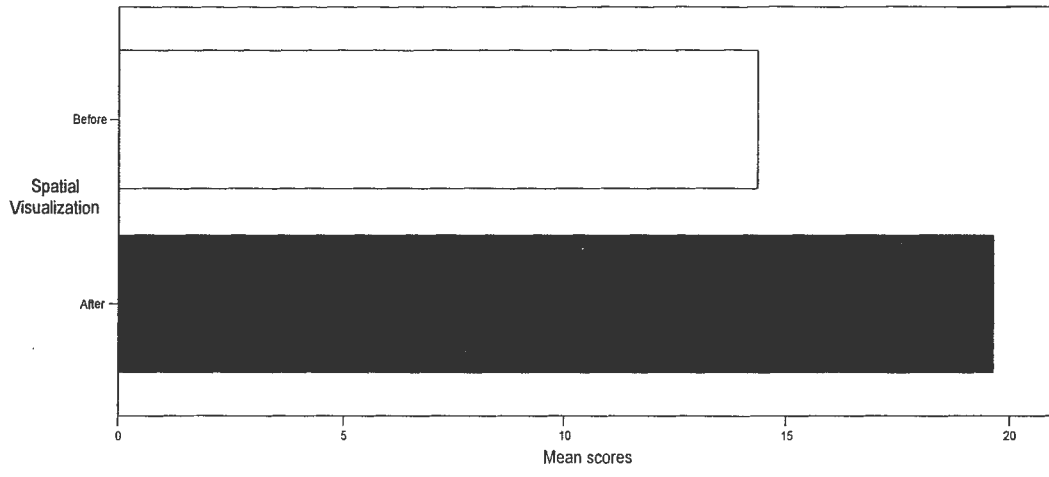



*Figure 5.1.* Pretest and posttest measures of spatial visualization

A *2-way ANOVA* was used to determine the main effects and interaction effects of training conditions and gender in this study. The means and standard deviations of spatial visualization after training by gender and training condition are summarized in Table 5.17 and Figure 5.2 on the following page.



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Table 5.17

*Means and standard deviations of spatial visualization after training by gender and training condition*

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| Gender | Training condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | interaction | | | animation | | | control | | |
| | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* |
| Girls | 12 | 19.42 | 3.77 | 12 | 16.67 | 3.54 | 12 | 19.75 | 3.58 |
| Boys | 21 | 25.07 | 3.28 | 21 | 18.65 | 5.57 | 20 | 16.73 | 6.21 |
| Total | 33 | 23.01 | 4.38 | 33 | 17.93 | 4.96 | 32 | 17.87 | 5.51 |

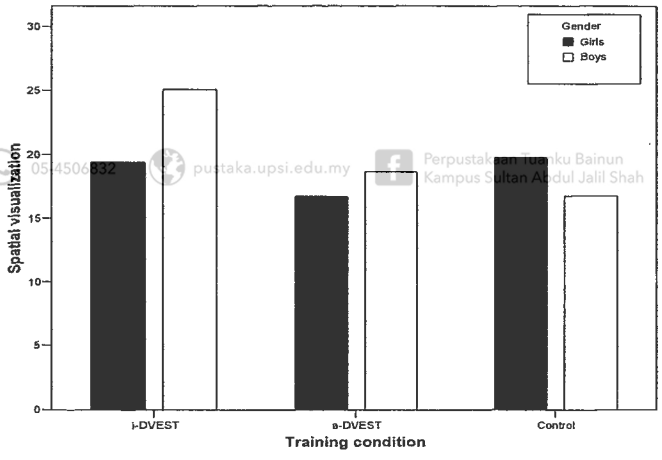



*Figure 5.2.* A bar plot for spatial visualization test scores after training by gender and training condition.

For the posttest measure of SV, the 33 participants in the interaction group had a mean of 23.01 (*SD* =4.38); the 33 participants in the animation group had a mean of 17.93 (*SD* = 4.96), and the 32 participants in the control group had a mean of 17.87



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(SD = 5.51). Table 5.18 shown below summarizes the results for the analysis of variance of the spatial visualization after training.

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Table 5.18
*Analysis of variance of spatial visualization after training*

| Source of variation | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Condition. | 379.645 | 2 | 189.823 | 8.709 | .000** |
| Gender. | 53.646 | 1 | 53.646 | 2.461 | .120 |
| Condition * Gender. | 286.192 | 2 | 143.096 | 6.565 | .002* |
| Error. | 2005.285 | 92 | 21.797 | | |
| Total. | 2724.768 | 97 | | | |

*p<.001, **p<.01

Results of the ANOVA revealed a statistically significant main effect for training condition, $F$ (2,92) = 8.71, $p$ = .001. Participants that trained in the interaction condition outperformed those trained in the other two training methods. Participants in the animation condition were better than those trained in the control condition. To determine where the differences among the training methods, the *Bonfferoni post hoc* test was employed to test for significance. All tests were conducted using the means of the spatial visualization scores. The post hoc test for the training condition variable was tested at the pre-established alpha level of .05. Comparison between the interaction-based training condition and the animation-based training condition revealed a mean difference of 5.08 and a significance of .001, indicating that there was significant difference between the two training methods.

The comparison between interaction-based condition and conventional condition revealed a mean difference of 5.15 indicating a significant difference (.001) between the two conditions of training that favored the former. A mean difference of .06 with significance level of .06 was observed when comparing animation-based training



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condition and conventional training condition, indicating a non-significant difference between participants' spatial visualization in these two groups. Thus, the results of the post hoc test provided evidence that there were significant spatial visualization differences where those trained in interaction-based condition performed better than the other two groups. Table 5.19 shown below summarizes the result of the post hoc test indicating the superiority of the former group compared to the latter two groups in the experimental study.

Table 5.19
*Bonferroni Post Hoc Test of the spatial visualization by training condition*

| (I) Training condition | (J) Training condition | (I-J) Mean Difference | Sig. |
|---|---|---|---|
| interaction | animation | 5.08* | .000* |
| | control | 5.15* | .000* |
| animation | interaction | -5.08* | .000* |
| | control | .06 | 1.000 |
| control | interaction | -5.15* | .000* |
| | animation | -.06 | 1.000 |

*p<.001

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In contrast, there was no significant main effect of gender, $F$ (1,92) = 2.46, $p$ = .12, where female and male participants performed equally well as shown in Table 5.19. The interaction between training condition and gender was found to be statistically significant, $F$ (2,96) = 6.57, $p$ = .002, indicating that the training effectiveness depended on the participants' gender.

Figure 5.3 shown overleaf illustrates the trend analysis of the spatial visualization performance mean scores by training condition and gender. The intersection of the slopes shows that the case where male participants were better at spatial visualization tasks than their female counterparts was found only in the interaction-based training condition. However, both genders were equivalent in their spatial visualization after training in the animation-based training condition. The same



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high performance of boys was not replicated in the control condition. In fact, female participants were better than their male counterparts were when trained using the conventional training method. The same figure highlights also the presence of an interaction effect between gender and the method of training employed in the experimental study.

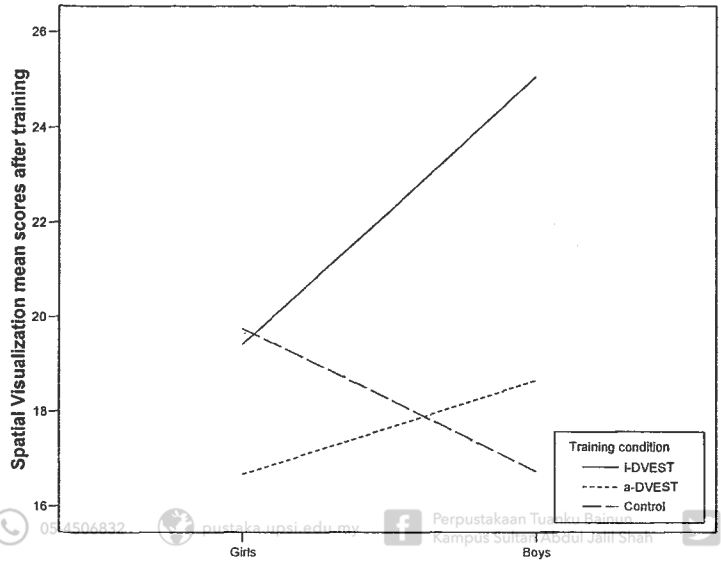



*Figure 5.3.* Trend analysis of mean spatial visualization performance scores by training condition and gender

## 5.4 Post-testing Measure of Mental Rotation Accuracy in the Experimental Research

Comparing the mean scores of the mental rotation accuracy before and after training using the paired t-test procedure revealed that the 98 participants had an average difference pre-test to post-test mental rotation accuracy scores of 3.37 (*SD* = 2.14). This indicates that mental rotation training resulted in a highly significant



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increase in mental rotation accuracy level, $t$ (97) = 15.63, $p$ = .001. Pretest and posttest measures of this ability are depicted in Figure 5.4 below.

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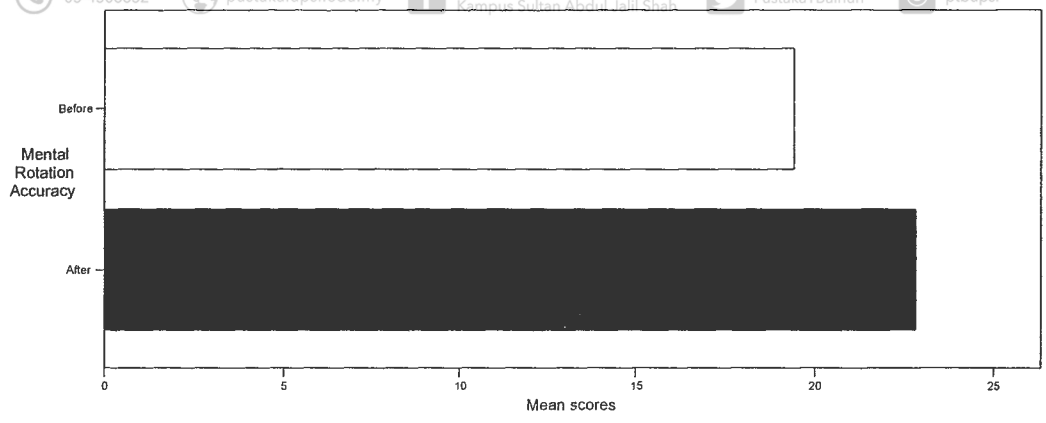



*Figure 5.4.* Pretest and posttest measures of mental rotation accuracy

The means and standard deviations of mental rotation accuracy after training by gender and training condition are summarized in Table 5.20 shown below and Figure 5.5 on the following page.

Table 5.20

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*Means and standard deviations for mental rotation accuracy after training by gender and training condition*

| Gender | Training condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | interaction | | | animation | | | control | | |
| | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* |
| Girls | 12 | 22.71 | 1.24 | 12 | 23.17 | 2.30 | 12 | 21.50 | 2.19 |
| Boys | 21 | 24.51 | 1.53 | 21 | 23.82 | 2.19 | 20 | 20.51 | 1.95 |
| Total | 33 | 23.86 | 1.67 | 33 | 23.58 | 2.22 | 32 | 20.88 | 2.06 |



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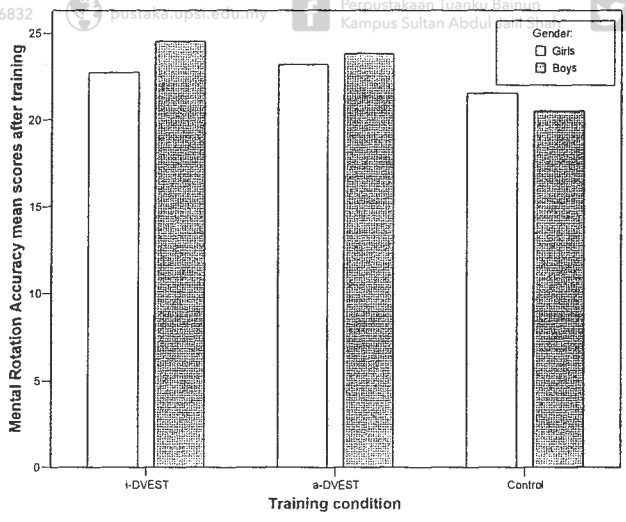



*Figure 5.5.* A bar plot for mental rotation accuracy test scores after training by gender and training condition

For the posttest measure of MRA, the 33 participants in the interaction-based training condition had a mean of 23.86 (*SD* =1.67); the 33 participants in the animation-based training condition had a mean of 23.58 (*SD* = 2.22), and the 32 participants in the control group had a mean of 20.88 (SD = 2.06). Table 5.21 shown below summarizes the result of the analysis of variance for mental rotation accuracy for the three groups.

Table 5.21
*Analysis of variance of Mental Rotation Accuracy (MRA) after training*

| Source of variation | Sum of Squares | df | Mean Square | F | Sig |
|---|---|---|---|---|---|
| Condition. | 130.750 | 2 | 65.375 | 17.486 | .000** |
| Gender. | 5.396 | 1 | 5.396 | 1.443 | .233 |
| Condition * Gender. | 29.676 | 2 | 14.838 | 3.969 | .022* |
| Error. | 343.967 | 92 | 3.739 | | |
| Total. | 509.789 | 97 | | | |

*p<.001,**p<.05



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The main effect of training condition was found to be statistically significant, $F(2,92) = 17.45$, $p = .001$ suggesting that training in different methods produced differential mental rotation accuracy performance. Ensuing pairwise comparisons using Bonfferoni post hoc test was employed to detect where the significant differences were among the three training methods. The interaction-based training condition was compared to the animation-based training condition revealing a mean difference of .27 and a significance of 1.00 that indicates that there was no significant difference between the two training methods as shown in Table 5.22 shown below. Comparing the interaction-based training condition with the control condition revealed a mean difference of 2.97 with significance level of .001, indicating a significant difference between the two types of training which favored the former method.

Table 5.22
*Bonferroni Post Hoc Test of mental rotation accuracy by training condition*

| (I) Training condition | (J) Training condition | (I-J) Mean Difference | Sig. |
|---|---|---|---|
| interaction | animation | .27 | 1.000 |
| | control | 2.97* | .000* |
| animation | interaction | -.27 | 1.000 |
| | control | 2.70* | .000* |
| control | interaction | -2.97* | .000* |
| | animation | -2.70* | .000* |

*p<.001

A mean difference of 2.70 with significance level of .001 was found when comparing the animation-based and control training methods indicating a significant difference between participants' mental rotation accuracy in the two groups favoring the former method. The result of the post hoc test provides evidence that significant mental rotation accuracy differences manifested between interaction-based group and control group, and between animation-based group and control group. No significant difference



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was found between the interaction-based group and animation-based group as showed in Table 5.22.

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The main effect attributed to gender was found to be not statistically significant, $F$ (1,92) = 1.43, $p$ = .23. Both genders made statistical similar gain in the improvement of their mental rotation accuracy irrespective of the training methods used. The interaction between training condition and gender was found to be statistically significant, $F$ (2,92) = 3.97, $p$ = .02. This implies that the effectiveness of the training methods depended on the gender of the participants. Figure 5.6 shown below illustrates the trend analysis of the mean mental rotation accuracy scores by training condition and gender. The intersection of the slopes indicates that there was an interaction effect between training condition and gender.

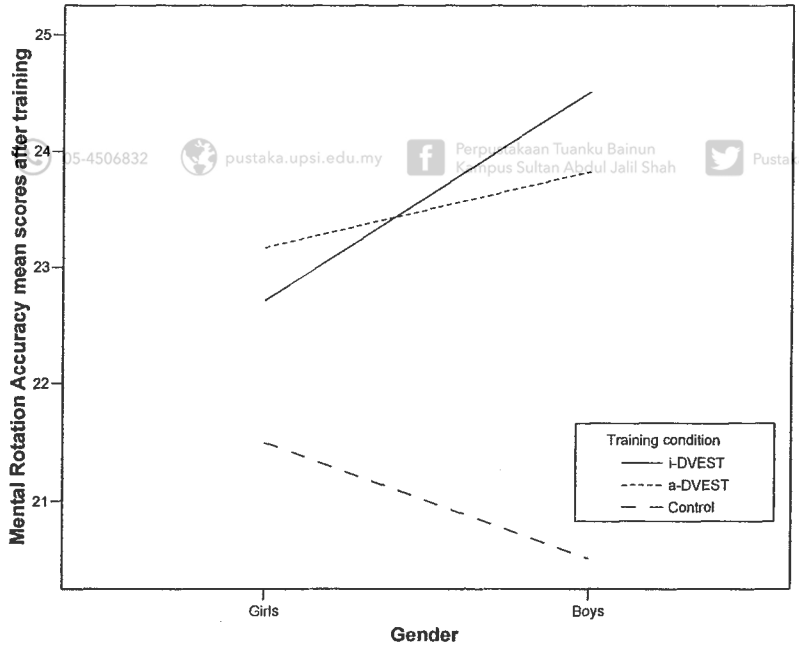



*Figure 5.6.* Trend analysis of mean mental rotation accuracy scores by training condition and gender



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Male participants trained in the interaction-based training condition were more accurate in mental rotation than female participants in the same setting. This pattern of differential performance gains favoring boys was also replicated in the animation-based training condition. However, female participants trained in the control condition were more accurate than their male counterparts were in this same group. Apparently, the use of novel training conditions benefited boys more that girls whilst conventional training seemed to be more effective for girls; thus, the novel methods were utilized advantageously by boys rather than girls.

## 5.5 Post-testing Measure of Mental Rotation Speed in the Experimental Research

Comparing the mean scores of the mental rotation speed before and after training using the paired t-test procedure revealed that the 98 participants had an average difference pre-test to post-test mental rotation speed scores of 3.37 (*SD* = 18.66). This indicates that mental rotation training did not result in a significant decrease in mental rotation speed, $t$ (97) = -1.78, $p$ = .08. The pretest and posttest scores for this ability are summarized in Figure 5.7 shown below.

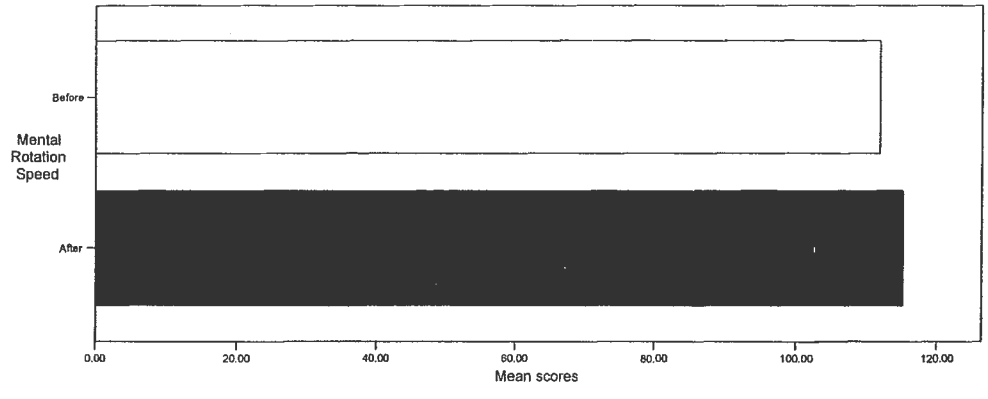



*Figure 5.7.* Pretest and posttest measures of mental rotation speed



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The means and standard deviations of mental rotation speed after training by gender and training condition are summarized in Table 5.23 and Figure 5.8 shown below.

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Table 5.23

*Means and standard deviations for mental rotation speed after training by gender and training condition*

| Gender | Training condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | interaction | | | animation | | | control | | |
| | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* |
| Girls | 12 | 115.50 | 21.71 | 12 | 117.00 | 22.10 | 12 | 103.71 | 20.07 |
| Boys | 21 | 111.50 | 27.57 | 21 | 116.33 | 24.81 | 20 | 123.33 | 26.40 |
| Total | 33 | 112.95 | 25.32 | 33 | 116.58 | 23.51 | 32 | 115.97 | 25.75 |

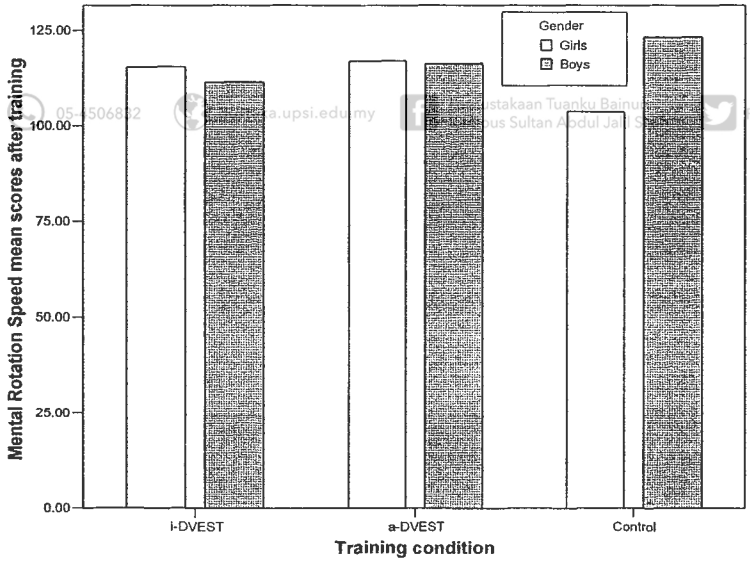



*Figure 5.8.* A bar plot for mental rotation speed scores after training by gender and training condition



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For the posttest measure of MRS, the 33 participants in the interaction-based training condition had an average reaction time of 112.96 seconds (*SD* = 25.32); the 33 participants in the animation-based training condition had an average reaction time of 116.58 seconds (*SD* = 23.51), and the 32 participants in the control condition had an average reaction time of 115.97 seconds (*SD* = 25.75). Table 5.24 summarizes the result of the analysis of variance for mental rotation speed for the three groups as shown below.

Table 5.24
*Analysis of variance of mental rotation speed after training*

| Source of variation | Sum of Squares | df | Mean Square | F | Sig |
|---|---|---|---|---|---|
| Condition. | 202.534 | 2 | 101.267 | .167 | .846 |
| Gender. | 565.488 | 1 | 565.488 | .933 | .337 |
| Condition * Gender. | 2465.862 | 2 | 1232.931 | 2.035 | .136 |
| Error. | 55734.533 | 92 | 605.810 | | |
| Total. | 58968.417 | 97 | | | |

The main effect of treatment condition was detected to be not significant, $F(2,92) = .17$, $p=.85$, indicating that participants' mental rotation ability for speed factor in the three groups after training were equivalent regardless of the method of training received. Similarly, the main effect of gender was not statistically significant, $F(1,92) = .93$, $p=.34$, where both genders attained similar performance after training. In addition, the interaction between gender and treatment condition, $F(2,92) = 2.04$, $p=.14$ were found to be not significant. For this measure of spatial ability, the spatial training had not made all the participants quicker in solving the mental rotation tasks as demonstrated in this experimental study. Close examination on the results revealed that the participants had in fact become slower (though not significant) after spatial training than they were before spatial training.



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## 5.6 Measurement of the Basic Engineering Drawing Task in the Experimental Research

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For the measure of basic engineering drawing performance, the 33 participants in the interaction-based training condition had a mean of 11.23 (*SD* =2.09); the 33 participants in the animation-based training condition had a mean of 9.67 (*SD* = 1.84), and the 32 participants in the control group had a mean of 9.62 (*SD* = 2.05). Table 5.25 shown below and Figure 5.9 shown on the following page summarize the descriptive statistics for means and standard deviations of the basic engineering drawing task performance by training condition and gender.

Table 5.25

*Means and standard deviations for engineering drawing task performance by gender and training condition*

| Gender | Training condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | interaction | | | animation | | | control | | |
| | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* | *n* | *Mean* | *SD* |
| Girls | 12 | 9.71 | 1.37 | 12 | 8.42 | 1.35 | 12 | 9.12 | 2.10 |
| Boys | 21 | 12.10 | 1.93 | 21 | 10.38 | 1.72 | 20 | 9.92 | 2.02 |
| Total | 33 | 11.23 | 2.09 | 33 | 9.67 | 1.84 | 32 | 9.62 | 2.05 |



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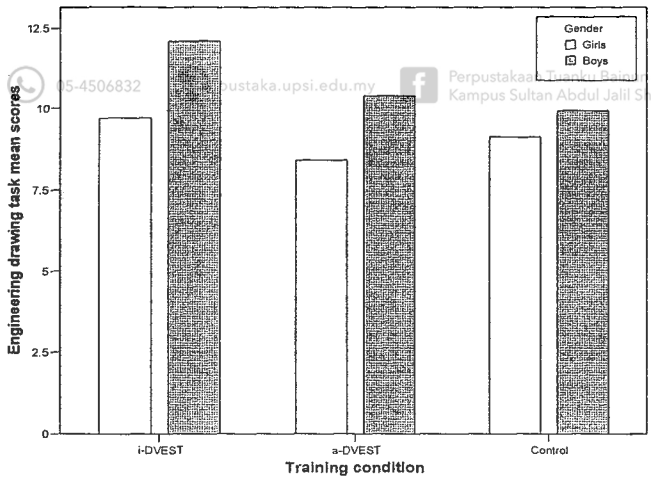



*Figure 5.9.* A bar plot engineering drawing task mean scores after training by gender and training condition

A two-way analysis of variance (2-way ANOVA) was used to determine if there were differences in the basic engineering drawing performance arising from the gender and training condition. Table 5.26 shown below reports the ANOVA results for differences in the mean performance scores of the participants by training condition, gender, and their interactions.

Table 5.26
*Analysis of variance for basic engineering drawing test performance*

| Source of variation | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Condition | 42.367 | 2 | 21.183 | 6.505 | .002* |
| Gender | 67.136 | 1 | 67.136 | 20.615 | .000** |
| Condition * Gender | 10.200 | 2 | 5.100 | 1.566 | .214 |
| Error | 299.608 | 92 | 3.257 | | |
| Total | 419.311 | 97 | | | |

*p<.01, **p<.001

As indicated in Table 5.26, a significant difference was found attributed to the main effect of the training condition, $F(2,92) = 6.51$, $p = .002$. A significant main effect of gender was also found, $F(1,92) = 20.62$, $p = .001$, indicating that boys outperformed girls in the basic engineering drawing task. The interaction between training condition and gender was found to be non-significant in this study, $F(2,92) = 1.57$, $p = .21$.

Significance testing of the differences in engineering drawing performance resulting from the three training methods were analyzed using the Bonfferoni post hoc test as shown in Table 5.27 below. A mean difference of 1.56 and a significance of .002 were observed when comparing the interaction-based training condition to the animation-based training condition indicating that there was a significant basic engineering drawing performance difference between the two training methods. Participants in the former method were better than the latter method in solving the engineering drawing problem. Comparing the interaction-based training condition with the control condition revealed a mean difference of 1.60 with significance level of .002 indicating a significant difference between the two types of training which favored the former method.

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Table 5.27

*Bonferroni Post Hoc Test of basic engineering drawing performance by training condition*

| (I) Condition of treatments | (J) Condition of treatments | (I-J) Mean difference | Sig. |
|---|---|---|---|
| interaction | animation | 1.56* | .002* |
| | control | 1.60* | .002* |
| animation | interaction | -1.56* | .002* |
| | control | .04 | 1.000 |
| control | interaction | -1.60* | .002* |
| | animation | -.04 | 1.000 |

*p<.01



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A mean difference of .04 with significance level of 1.00 was detected when comparing the animation-based group and the control group. There was no significant difference between these two conditions with respect to the participants' performance in basic engineering drawing task. The result of the post hoc test provides evidence that significant basic engineering drawing performance differences manifested only between the interaction-based group and animation-based group, and between the interaction-based group and the control group. No significant difference was found between the animation-based group and control group.

## 5.7 Prediction of Critical Factors for the Performance of the Basic Engineering Drawing Task

The Multiple Linear Regression (MLR) procedure was employed in order to predict more accurately which factors that had significant influence on participants' performance in solving basic engineering drawing problem. The use of Multiple Regression for prediction is entailed when one is using a sample to create a regression equation that would optimally predict a particular phenomenon within a particular population (Osborne, 2000). The main objective here is to create the best equation so that, for example, a teacher could predict her or his students' performance in undertaking engineering drawing task in the future. Having identified the critical factors, the teacher can intervene by taking the necessary steps to help those students identified as at risk for lacking the necessary skills to learn the subject matter. The statistical model employed in the study comprised four predictor (independent) variables and a criterion (dependent) variable. The four predictor variables were gender, spatial visualization (SV), mental rotation accuracy (MRA), and mental rotation speed (MRS); the criterion variable in the statistical model was the mean scores of basic engineering drawing task. All the four predictor variables were simultaneously entered into the MLR equation for the analysis.



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The relations between basic engineering drawing task performance and the independent variables were first computed. Interrelations among the independent variables were also determined prior to the MLR analysis. Table 5.28 shown below summarizes the *bivariate* correlations of the factors at the level of significance of .05

Table 5.28
*Pearson correlation matrix of interrelations among engineering drawing performance, gender and spatial abilities*

| **Measures** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| 1. Basic engineering drawing performance. | -- | .397* | .736** | .251* | -.263** |
| 2. Gender. | | -- | .140 | .107 | .096 |
| 3. Post spatial visualization. | | | -- | .320** | -.375** |
| 4. Post mental rotation accuracy. | | | | -- | -.221* |
| 5. Post mental rotation speed | | | | | -- |

*p<.05, **p<.01

As shown in Table 5.28, the correlation between basic engineering drawing task performance and gender was significant and moderately strong , $r(97) = .40$, $p = .001$, suggesting that male participants were better in solving the task compared to their female counterparts. A significant and positively strong correlation was established between post spatial visualization and basic engineering drawing task performance, $r(97) = .74$, $p = .001$. Participants that had higher spatial visualization skill performed better in engineering drawing compared to those of relatively lower spatial visualization



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ability. The correlation between post mental rotation accuracy and basic engineering drawing task performance was significant but low in strength, $r(97) = .25$, $p = .013$. In general, participants that were more accurate in mental rotation were better in solving the engineering drawing task. The correlation that was established between post mental rotation speed and basic engineering drawing task performance was significant but weak in strength, $r(97) = -.26$, $p = .009$, indicating that in general participants whose reaction times were faster performed better in engineering drawing task compared to those relatively slower in this mental rotation measure.

No significant correlation between gender and spatial visualization was found in this study. Likewise, correlations between gender and mental rotation abilities were also not significant. Interrelation between spatial visualization and mental rotation accuracy was found to be significant and small, $r(97) = -.32$, $p = .001$. Likewise, spatial visualization and mental rotation speed was found to be significant and small in strength, $r(97) = -.30$, $p = .001$. In general, participants with high spatial visualization ability were also correspondingly faster and accurate in mental rotation. A negative correlation between the accuracy and speed measures of mental rotation was found to be significant but low in strength, $r(97) = -.22$, $p = .03$. Generally, participants who were quick in mental rotation task were also more accurate in mental rotation task.

The assumptions of the MLR procedure were first tested prior to its use, namely the *normality, linearity, multicollinearity* and *homoscedasticity*. Initially, these assumptions were tested by visual inspection of the relevant graphs produced by the statistical package. Visual inspection of the histogram of the residuals with a normal curve superimposed showed that a normal distributional profile (see details in Appendix 16.0). Likewise, the Normal P-P Plot of Regression Standardized Residual (see details in Appendix 17.0) shows that the data follows a straight line thus satisfying the assumptions of normality. For homoscedasticity testing, the graph of the Regression Standardized Residuals against Regression Standardized Predicted Value shows



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constant variance across levels of the dependent variable (see details in Appendix 18.0). The assumption of no multicollinearity among the independent variables was met when each of the calculated *variance inflation factors* (VIF) was far below the critical value of '10' as cautioned by Leech et al. (2005) (see details in Appendix 19.0).

The linear combination of gender and the measures of SV, MRA and MRS was significantly related to the performance of basic engineering drawing task, $F$ (4,93) = 39.77, $p$ = .001. The multiple correlation coefficient, $R$ was .79, indicating that approximately 63% (i.e., $R^2$ = .63) of the variance of the performance in basic engineering drawing task can be accounted for by the linear combination of these spatial abilities and gender factor as summarized in Table 5.29 shown below.

Table 5.29
*Analysis of variance for model regressing on basic engineering drawing test scores*

| Source of variation | Sum of Squares | df | Mean Square | F | R | $R^2$ | Sig. |
|---|---|---|---|---|---|---|---|
| Regression | 272.693 | 4 | 68.173 | 39.767 | .794 | .631 | .000* |
| Residual | 159.432 | 93 | 1.714 | | | | |
| Total | 432.125 | 97 | | | | | |

*$p$<.001

With other variables held constant, the performance of basic engineering drawing task was positively related to spatial visualization but negatively related to mental rotation accuracy and speed factors as summarized in Table 5.30 shown on the following page. In general, those who had better spatial visualization ability and mental rotation abilities tended to perform better than others who had lower abilities. In addition, male participants tended to outperform their female counterparts in undertaking such an engineering drawing task.



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Table 5.30

*Standard Regression Model summaries for gender and spatial ability variables*

| | Unstandardized Coefficients | | Standardized Coefficients | *t* | Sig. |
|---|---|---|---|---|---|
| | B | Std. Error | Beta | | |
| (Constant) | 4.735 | 1.631 | | 2.903 | .005 |
| Post_MRA | -.007 | .059 | -.008 | -.123 | .902 |
| Post_MRS | -.003 | .006 | -.038 | -.550 | .584 |
| Post_SV | .262 | .027 | .681 | 9.544 | .000** |
| Gender | 1.334 | .282 | .306 | 4.734 | .000** |

**$p<.001$

The effects of gender ($t_{93} = 4.73, p = .001$) and spatial visualization ($t_{93} = 9.54, p = .001$) were the only significant factors in predicting the performance in such task in this study. The effects of the other factors namely mental rotation abilities were found not to be statistically significant to account for the variance in the performance of such an engineering drawing task.

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A stepwise multiple linear regression was also conducted to evaluate whether the gender and spatial ability factors were necessary to predict the performance of basic engineering drawing task. For the statistical model, the researcher set the entry level of significance to .05 such that for the variable to be included in the model, it must explain at least 5% of the basic engineering drawing performance's variance. The level of significance to remain in the model was set to .05 or 5% of the variance in the performance. After two iterations of the procedure, no more changes in the model composition occured.

For the first model of the analysis, post spatial visualization measure first entered into the regression equation; this spatial measure was detected to be



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significantly related to basic engineering drawing task performance, $F(1,96) = 113.43$, $p = .001$ as shown in Table 5.31 below.

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Table 5.31

*Analysis of variance for stepwise regression models regressing on basic engineering drawing test scores*

| Model | Source of variation | Sum of Squares | df | Mean Square | F | R | $R^2$ | Sig |
|---|---|---|---|---|---|---|---|---|
| 1 | Regression | 234.042 | 1 | 234.042 | 113.427 | .736 | .542 | .000** |
| | Residual | 198.083 | 96 | 2.063 | | | | |
| | Total | 432.125 | 97 | | | | | |
| 2 | Regression | 272.170 | 2 | 136.085 | 80.823 | .794 | .630 | .000** |
| | Residual | 159.955 | 95 | 1.684 | | | | |
| | Total | 432.125 | 97 | | | | | |

** $p<.001$

The multiple correlation coefficient of the model was .74, indicating that approximately 54% ($R^2$ = .54) of the variance of the performance in the basic engineering drawing task can be accounted for by the spatial visualization factor where the main effect attributed to this sub-skill of spatial ability was statistically significant, ($t_{96} = 10.65$, $p = .001$). Table 5.32 shown on the following page shows the summaries for the gender and spatial ability measures based on the stepwise regression model used in the analysis.



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Table 5.32

*Stepwise Regression Model summaries for gender and spatial ability measures*

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| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 4.624 | .541 | | 8.541 | .000 |
| | Post spatial visualization. | .283 | .027 | .736 | 10.650 | .000** |
| 2 | (Constant) | 4.115 | .501 | | 8.220 | .000 |
| | Post spatial visualization. | .267 | .024 | .694 | 11.005 | .000** |
| | Gender. | 1.307 | .275 | .300 | 4.759 | .000** |

** $p<.001$

Gender factor entered into the regression equation in the second model of the analysis, where both the spatial visualization and gender factors were significantly correlated with basic engineering drawing task performance, $F(2,95) = 80.82$, $p = .001$. The multiple correlation coefficient was .79, indicating that approximately 63% ($R^2 = .63$) of the variance of the performance of basic engineering drawing task can be accounted for by the linear combination of the spatial visualization and gender factors (see model 2 in Table 5.31). In other words, the increase in the multiple correlation coefficient in the second model was attributed to the effect of gender. The $R$ square change in the second model was .09, indicating that gender explained 9% of the variance in basic engineering drawing task performance in the statistical model for the regression analysis.

The stepwise MLR analysis revealed that, in general, those having superior spatial visualization ability or skill were better in solving the basic engineering drawing task than those with relatively lower spatial visualization ability. Male participants



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were more able to achieve better performance in similar task compared to their female participants. The effects due to spatial visualization ($t_{95}$ = 11.00, $p$ = .001) and gender ($t_{95}$ = 4.76, $p$ = .001) were statistically significant in predicting the performance in such a task in this study based on the stepwise MLR analysis as summarized in Table 5.32.

Other psychometric variables namely the mental rotation accuracy ($t_{93}$ = -.123, $p$ > .05) and mental rotation speed ($t_{93}$ = - .55, $p$ > .05) did not enter into the regression at the stepwise procedure of the analysis as these factors did not have significant effects in accounting for the variance in the performance of basic engineering drawing task as summarized in Table 5.30.

## 5.8 Students' Perception on the Training Effectiveness, Spatial Cognition And System Usability

A 12–item questionnaire with one open-ended question was administered to every student after the completion of the training (see Appendix 12.0). This instrument measured the participants' perceptions on essential training factors, namely training effectiveness, spatial cognition, and system usability where the latter was only applicable to the experimental conditions. Each item's response is rated along a Likert-type scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). The open-ended question helped reveal greater insight about the training experienced by the participants. A professor who has vast expertise in educational research reviewed the questionnaire; then the researcher used reflective analysis to evaluate a phenomenon relying on intuition and judgment as recommended by Gall, Borg, and Gall (2003). All the comments and feedback from the open-ended question were translated from Malaysian language into English by the researcher. Table 5.33 shown on the following page summarizes the responses of the participants for perceived training effectiveness,



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improved spatial cognition, and application usability based on training condition and gender shown below.

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Table 5.33

*Mean scores of students' perception of training effectiveness, improved cognition and application usability based on training condition and gender*

| Students' perception measures | Training condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | interaction | | | animation | | | control | | |
| | Girls ($n$ =12) | Boys ($n$=21) | All ($n$=33) | Girls ($n$=12) | Boys ($n$=21) | All ($n$=33) | Girls ($n$=12) | Boys ($n$=20) | All ($n$=32) |
| Training effective-ness | 4.08 | 4.24 | 4.18 | 3.50 | 3.76 | 3.67 | 3.42 | 2.05 | 2.56 |
| Improved cognition | 3.58 | 3.86 | 3.76 | 3.17 | 3.57 | 3.42 | 3.50 | 1.90 | 2.50 |
| Application usability | 3.00 | 4.19 | 3.76 | n/a | n/a | n/a | n/a | n/a | n/a |

*Note.* The notation 'n/a' stands for 'not available'

The mean scores for perceived training effectiveness in the interaction, animation, and control groups were 4.18, 3.67, and 2.56 respectively. The mean scores for perceived training effectiveness reported by girls were 4.08, 3.50, and 3.42 for interaction-based, animation-based, and conventional training conditions, respectively; and for boys, the mean scores were 4.24, 3.76 and 2.05, respectively. For perceived improved spatial cognition, the mean scores for interaction, animation, and control groups were 3.76, 3.42, and 2.50 respectively. The mean scores for perceived improved spatial cognition as reported by girls were 3.58, 3.17, and 3.50 for interaction-based, animation-based, and conventional training conditions respectively; and for boys, the mean scores were 3.86, 3.57, and 1.90 respectively. The mean scores for perceived application usability as reported by all the participants in the interaction-based training condition were 3.76, with girls and boys registering mean scores of 3.00 and 4.19, respectively.



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The information elicited from the comments and feedback of the open-ended question provides a qualitative measure of the spatial training experienced by the participants. Their comments were examined and classified according to several themes or issues pertaining to spatial cognition, effectiveness of training and usability of the spatial trainer. From the 98 participants involved in this study, only 32 of them recorded their comments as summarized in Table 5.34a and Table5.34b shown on the following two pages.

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Table 5.34a

*Comments regarding the spatial cognitive aspects after spatial training (Part A)*

| Themes | | Some examples of responses ('+' and '—' signs refer to positive and negative comments respectively) | Training Conditions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | interaction | | | animation | | | control | | |
| | | | Girls | Boys | All | Girls | Boys | All | Girls | Boys | All |
| *Cognitive* | + | <u>interaction-enabled :</u><br>"…it helped me see objects more clearly from multiple angles/ I could rotate an object making it easier to see hidden faces or planes/ I understand better with more trials (practice)/ I was able to figure out the planes of objects after some efforts / I got some visual cues to solve the stack of blocks from certain directions/ twisting and rotating revealed a clear 'picture' of objects/ I took some time to interact to solve difficult problems/ If I was stuck, I explored to 'see' clearly ".<br><br><u>animation-enhanced :</u><br>"…steps to solve problems were made clear through animations/ it gave me some ideas to solve the problems/ I used this feature when it got me nowhere!/ it allowed me to make connection of what to do next/ I trained better when I could see the clear process". | 4 | 11 | 15 | 3 | 10 | 13 | 0 | 0 | 0 |
| | — | <u>animation-enhanced :</u><br>"…I couldn't imagine the complex arrangements".<br><br><u>control :</u><br>"…the objects were not that easy to imagine/ I had no ideas how to solve when everything was blurry/ some of the objects confused me!" | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 2 | 3 |



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Table 5.34b

*Comments regarding the training effectiveness and usability after spatial training (Part B)*

| Themes | | Some examples of responses ('+' and '—' refer to positive and negative comments respectively) | Training Conditions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | interaction | | | animation | | | control | | |
| | | | Girls | Boys | All | Girls | Boys | All | Girls | Boys | All |
| *Training effectiveness* | + | interaction-enabled :<br>"…I think I can solve spatial problems better after training/ My skill has improved/ I can handle spatial problems with fewer errors through constant practice/ Overall, I think I am okay!"<br>animation-enhanced :<br>"…now, I can solve problems better/ I think I will be good in solving tasks of this kind/ The training was quite good in making me more skilful".<br>control :<br>"…this training has made me quite good/ …through training, I was more confident". | 5 | 8 | 13 | 4 | 7 | 11 | 5 | 1 | 6 |
| | — | animation-enhanced :<br>"… no major impact in my ability to handle problems"<br>control :<br>"…I don't think I have made great progress/ it makes no difference with training/ I need more practice to help me get through! / " | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 3 | 4 |
| *Usability* | + | interaction-enabled :<br>"…the interface was not that difficult to use / interacting with objects seems similar to some games/ at first I got stuck but it was okay later/ with some practice, I could easily 'control' objects. | 1 | 9 | 10 | not applicable | | | not applicable | | |
| | — | interaction-enabled:<br>"…I sometimes got 'conflicting' views when I used the mouse to 'move'/ it was quite a struggle getting used to this environment/ Occasionally, the movements in certain directions were unpredictable making me lost" | 6 | 0 | 6 | not applicable | | | not applicable | | |

Fifteen respondents (4 girls, 11 boys) reported that training by means of interaction with the virtual objects helped them visualize better the various parts of objects and their spatial configuration and arrangement in solving the spatial tasks as shown in Table 5.34a. Comments such as "helped me see objects more clearly from multiple angles" or "I could rotate an object making it easier to see hidden faces or planes" are indicative of the improved spatial cognition resulting from training through interaction-based condition. For animation-based training in the spatial trainer, 13 respondents (3 girls, 10 boys) reported that animations provide them with perceptual clues during problem solving. Comments such as "...steps to solve problems were made clear through animations" or "...it allowed me to make connection of what to do next" are some of the evidence that suggest animations serve as a cognitive scaffold that helped some of the participants to solve the spatial tasks. For this type of training, only one respondent gave a negative feedback. For training based on the conventional approach, the comments from three respondents (1 girl, 2 boys) indicated that their spatial cognition had not improved.

From Table 5.34b, 13 respondents (5 girls, 8 boys) who trained in interaction-based condition reported that training was effective as inferred from comments such as "...I think I can solve spatial problems better after training" and "I can handle spatial problems with fewer errors through constant practice". Likewise, 11 respondents (4 girls and 7 boys) indicated that training aided by animations was effective through comments such as "I think I will be good in solving tasks of this kind" and "the training was quite good in making me more skilful". However, only one respondent (i.e., a girl) indicated spatial training assisted by animations was not effective as informed from her feedback namely "... no major impact in my ability to handle problems". For training using printed materials in the control group, six respondents (5 girls, 1 boy) reported that training was effective in improving their spatial skills as deduced from some of the comments such as "...this training has made me quite good" and "...through training, I am more confident".

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On the other hand, four respondents (1 girl, 3 boys) indicated that training using the conventional approach had no training effect. For usability factor such as navigation in the virtual environment, 10 respondents (1 girl, 9 boys) expressed their views that they were able to use the interface for interaction without too much difficulty. Apparently, some of the participants already had some prior experience as reported by their comments notably the feedback "interacting with objects seems similar to some games". However, six female respondents did indicate that they were having trouble when using this novel environment in training as shown in Table 5.34b. Apparently, a statement that reads "...it was quite a struggle getting used to this environment" suggests interacting within the virtual scene was problematic to the girls that may be attributed to low navigational skills.

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## 5.9 Summary

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Pre-testing of the spatial ability indicated that at the outset of the interventional treatment all the groups and gender were equivalent. For spatial visualization (SV), improvement gains were highest in interaction-enabled method, moderate in animation-enhanced method and low in conventional method. For mental rotation accuracy (MRA), improvement gains were lowest in conventional method and were equivalent for both the interaction-enabled and animation-enhanced methods. For mental rotation speed (MRS), there was no significant gain after training for all the three training groups. However, gender effects for all the three spatial measures were found to be non-significant. In addition, interaction effects between method of training and gender were observed, where interaction-based condition favored boys, animation-based condition was gender-neutra,l and conventional condition disadvantaged boys. For performance of basic engineering drawing task, those trained in interaction-enabled condition outperformed the other two groups owing to the former's higher spatial visualization gained through training. Effectively, this particular finding indicates a training transfer from spatial training (i.e., knowledge construction) to solving engineering drawing task (i.e., knowledge application). Findings from regression analysis verified that spatial visualization was the only factor that significantly explained the variance of performance in basic engineering drawing task in this study.

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# CHAPTER 6

# DISCUSSION, RESEARCH CONTRIBUTIONS AND FUTURE RESEARCH

## 6.0 Introduction

Significant and moderately strong correlation between perceived ability (i.e., self-efficacy) to learn engineering drawing (especially for high spatial content topics) and spatial experience was found based on the survey research. In general, students reported difficulty in learning high spatial content topics such as isometric projection, orthographic projection, and auxiliary views. In addition, males tended to regard themselves high in spatial experience compared to their female counterparts. The correlation between perceived ability and previous mathematics achievement was significant but low in strength. Similarly, the correlation between perceived ability and gender was also significant but weak in strength. Regression analysis attested that spatial experience was the only variable that have strong predictive power to account for variation in students' perceived ability to learn engineering drawing at the foundational year.

The training of spatial ability in the experimental research yielded significant improvement in spatial visualization and, to a lesser extent, mental rotation accuracy. The improvement of mental rotation speed was marginal indicating that there was no significant training effect in making the participants faster in this measure. Overall, training in the novel conditions, in particular, the interaction-enabled method had been efficacious compared to the conventional method. Evidently, having the ability to navigate and interact in the 3D generated virtual environment engendered a training environment that aided in greater visual perception leading to efficient mental operations in solving spatial visualization and mental rotation tasks. To some extent, animations were found to have a positive effect in spatial training facilitating the correct

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mental schema in solving similar tasks. Thus, the combination of interaction and animation can be a beneficial feature in spatial training.

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In addition, gender seemed to play a mediating role in that boys in general appeared to have gained different training effects: high in virtual environment, moderate in animation-enhanced condition, and low in conventional method. However, these different performances were not replicated for female participants suggesting that spatial training based on technology-enhanced setting can be beneficial only to a particular gender, but not necessarily effective to the opposite gender. Training transfer was detected as the group with higher spatial ability gained from training outperformed those groups of lower spatial ability. Regression analysis confirmed that solving an engineering drawing task seemed to tap more on spatial visualization than mental rotation that was contributive for the training transfer. Clearly, spatial training in interactive desktop virtual environment engendered higher spatial visualization skill enabling better performance in solving the engineering drawing task. Emphasis should be given to spatial visualization training that is deemed vital in learning domains entailing this ability, namely engineering drawing course.

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## 6.1 Discussion on the Survey Research

Findings from the survey study provide important insights concerning the perceived ability of students to learn the subject matter based on several demographics. First, gender appears to be one of the detrimental factors in the participants' perception of learning engineering drawing in this survey. Overall, male participants surveyed indicated higher perceived ability to follow the instructions of engineering drawing involving topics of high spatial loading compared to female participants, thus supporting the first hypothesis (i.e., $H_i$) for the gender factor of the study. However, an opposite direction of perception between gender groups was detected where females reported higher ability to learn the topics of low spatial content than males. These two

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topics cover the basic facts and explanations on engineering drawing practices. Thus, one plausible explanation for female higher perception of learning the low spatial content topics is the notion that, in general, females have greater ability to study contents of learning requiring a learning approach based on memorization and recall of facts rather than spatial skills favoring verbal over spatial learners (Gurian & Stevens, 2005).

The relationship between previous mathematics achievement and participants' perceived ability to learn engineering drawing was found to be significant but the strength of the association was quite small. Thus, the first hypothesis (for the mathematical ability) of this survey research study was not supported, indicating that the perception of learning the subject matter was not dependent on students' mathematical background. Spatial experience has been established to be one of the critical factors having a significant positive relationship with students' perceived ability to learn engineering drawing only for high spatial content topics, thus supporting the first research hypothesis (for the spatial experience factor) of the study. The association between these two factors was significant and its strength was moderate. Apparently, the higher the students' level of spatial experience the higher their perceived ability to learn the subject matter particularly for topics of high spatial contents. On the other hand, respondents having low level of spatial experience would experience greater difficulty in learning these topics. In addition, the association between spatial experience and perceived ability to learn topics of low spatial contents was non-significant and very low. From the cognitive perspective, learning these low spatial topics does not utilize spatial processing of visuo-spatial information whereas learning high spatial contents entails such an approach. Not surprisingly, the majority of the respondents tended to report higher ability to learn these topics of low spatial contents.

The analysis of interrelations among the variables revealed that there was a significant but weak relationship between gender and previous mathematics

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achievement favoring male respondents. This is not surprising as the survey involved greater number of male students over female students and more male students indicated having relatively better grades than female respondents did. This imbalance of gender distribution reflects the traditional male dominance in science and technical education, attributing to their high enrolment where academic pursuit in that area of education is influenced by social and cultural contexts. Similarly, the correlation between gender and spatial experience was found to be significant and small in strength. In general, male respondents were of higher spatial experience than their female counterparts were. More often than not, males would have greater exposure to spatial experiences through games, play, and sports that nurture spatial skills compared to females' engagement in activities that is lacking in spatial components. Also established in this study was a significant but small correlation between spatial experience and previous mathematics achievement. Generally, high achievers in mathematics had more experience in spatial activities compared to low achievers. Literature of mathematics learning is replete with evidence suggesting strong relation between these two factors (Gallagher & Kaufman, 2005). Examining all these factors and their interactions together, a pattern emerged suggesting that, in general, male participants tended to have higher spatial experience and mathematics background. In unison, these factors apparently resulted in males' relatively higher perceived ability to learn engineering drawing compared to their opposite counterparts.

Ensuing statistical analyses employing four models of the multiple regression procedure further highlighted that gender, previous mathematics achievement, and spatial experience were highly correlated with the participants' perceived ability to learn engineering drawing. In the three regression models, all the three predictor variables were found to be significant to account for the variances of the perceived ability to learn all topics, the topics of high spatial contents, and the topics of moderate spatial contents. The model employing low spatial content topic that resulted in less variance explained was considered a poor fit. This was not unexpected as the loading of

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spatial factor in predicting perceived ability to learn engineering topics of low spatial content was too small to be accounted in the statistical analysis. The learning of these topics normally requires rote learning and recall of facts and techniques which does not tap on spatial cognition. Additional regression analyses using stepwise regression procedures further attested to the predictive power of gender, previous mathematics achievement, and spatial experience that explained the total variation of the perception of learning.

The above findings can help improve current instructional method of engineering drawing by recognizing the potential differences in perceived ability to learn arising from several demographic factors in particular spatial experience. Teachers and instructors need to be aware of these differences among individuals or groups to undertake appropriate and necessary teaching strategies in their classrooms. Another important finding was the revelation of substantial gender difference in spatial experience. In general, female students were less spatially experienced than males, which may translate into potential learning problem in engineering drawing instruction, the domain of learning requiring high spatial visualization skills. Female students in this course may come from disadvantaged background with less spatial experience, predisposing them to a difficult situation where the contents of learning are perceived to be cognitively challenging. This particular group of students may be highly vulnerable to academic threats such as anxiety or fear, discouraging them from concentrating and remaining focused throughout the process of learning. Teachers and instructors should be aware of these potential differences in their classrooms given today's social emphasis on gender equality that has resulted in better female representation in schools and other academic institutions.

It should be emphasized that the findings of this survey study were based on self-reported measures that have to be taken with caution. However, cautionary steps had been taken to reduce any internal and external threats to the study following the

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administration of the questionnaire. As stated in the method section, the researcher was present during the data collection exercise at the school where explicit information and instructions to respondents were made. Confidentiality and anonymity were assured to the students and it was made clear that their participation was based on voluntary basis. Through this assurance and consistent administration, the participants were made more confident to report their experience without prejudice, thus controlling any systematic bias and random variance. In addition, internal consistency testing was performed and expert judgment was used to ensure that all instruments employed in the survey were reliable and valid.

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## 6.2 Conclusion of the Survey Research

The research findings have highlighted that some topics of engineering drawing at the foundational year consist of high spatial contents, namely multi-view orthographic drawings, isometric drawings, and auxiliary views that require greater spatial ability or skills. Teachers and instructors may have to prepare extra or extended classroom activities in the teaching process especially in dealing with topics that are considered difficult by some of the students. Interventional programs could be planned and implemented in the classroom activities. These include providing remedial activities to allow weak students to practice and train to enrich their spatial experience thus enhancing their spatial ability.

Several research studies in addressing students' lack of experience in spatial activities through interventional programs have been demonstrated to be quite promising in enhancing spatial skills. These spatial skills include both the mental rotation and spatial visualization, which are widely recognized to be important in learning science and technical fields. These novel and innovative tools provided

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opportunities for learners to engage specific spatial tasks focusing on the spatial visualization skills and reasoning, making them more proficient in problem solving.

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A broader implication of students' perceived ability to learn is linked to its important role in all cognitive theories of motivation involving several motivational constructs such as self-efficacy. Bandura (1986) posits this construct as individuals' confidence in their ability to control their thoughts, feelings, and actions thus influencing an outcome. The lower the perceived ability to learn, the higher is the risk of losing confidence and motivation in the learning process; this, in turn, may translate into poor performance. The resilience of the students may be tested where some may give up as they have doubts about their abilities while others may persevere (Suppiah, 2005). In this context, it is critical that students' motivation in the process of learning engineering drawing to be given due attention and monitored by teachers and instructors to ensure that pupils would tap on appropriate reasoning (i.e., spatial thinking) and also to maintain persistent engagement throughout the learning process.

The standard practice by Malaysians school agencies to impose relatively high previous mathematics achievement at Form Three level (i.e., at ninth grade) of the secondary school system for entry requirement may not adequately address low passing rates in engineering drawing course. In addition, spatial experience of students opting for this course may have to be made one of the criteria in the selection process. Early assessment of their experiences and skills in spatial activities is vital for students pursuing courses in engineering graphics or CAD given the strong association between these factors with the course performance ( Alias, Black, & Gray, 2002; Scales & Kirby, 2000; Suppiah, 2005). This survey research has discovered important finding in terms of understanding the relationships among factors that are vital in the instructions of engineering drawing course taught at the foundational year in Malaysian secondary schools. All the factors investigated, namely gender and spatial experience were found to be detrimental factors to the participants' perception of their ability to learn

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engineering drawing; therefore, these factors need to be factored into the instructional activities particularly for low spatial experience learners and female students.

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More important, the knowledge and information gained from this survey research have highlighted the critical role played by spatial experience and gender. Female and low spatial experience students viewed learning of the subject matter to be challenging especially for high spatial content topics such as multi-view orthographic drawings. Spatial experience is particularly indicative of a pupil's level of spatial ability that is vital in learning domains requiring greater use of spatial cognition or thinking in challenging fields such as engineering, architecture, graphics, and science. The literature of cognitive science has documented a number of studies indicating strong correlation between spatial experience and spatial ability involving children and adults. In general, individuals with greater exposure to and experience in activities tapping on spatial cognition or skills would exhibit higher scores on tests of spatial ability such as spatial visualization and mental rotation.

The above findings set the premise and context for the experimental research focusing on enriching the participants' spatial experience by means of spatial ability training. The research that followed stressed on specific components of spatial ability namely spatial visualization and mental rotation deemed critical cognitive skills or abilities required for the instructions of engineering drawing in secondary schools (Olkun, 2003; Prieto & Velasco, 2004; Roorda, 1994). This entailed the design and development of a spatial training platform (see details in Chapter 4) informed through the current theory of learning for optimal training effect using relevant training materials that was mediated by computer technology for efficient instructional delivery. The use of the training application helped the participants to train in spatial reasoning of the specific components of spatial ability in particular spatial visualization and mental rotation rather than generic skills. Upon the completion of the spatial training in spatial visualization and mental rotation, it was imperative that the transfer of these abilities

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from training to solving an engineering drawing task involving a multi-view orthographic drawing be examined.

## 6.3 Spatial Visualization and Mental Rotation prior to Spatial Training in the Experimental Research

Prior to the spatial training experiment, all groups were established to be statistically equivalent in terms of their spatial visualization and mental rotation abilities in the study. This was very crucial to ensure that resultant outcomes of the spatial training which may differ among the three groups can be explained from the premise and contexts of the effects of the training methods that the participants received. Otherwise, the training effects were likely to be confounded by their prior differences in these abilities. Further examination of the groups based on gender revealed an interesting finding where there were no gender differences in spatial visualization and mental rotation abilities, indicating that both male and female participants were equivalent. This was quite surprising given ample evidence that highlights spatial ability superiority of males over females in most literature, especially in mental rotation as highlighted by Halpern (2000), Linn and Hyde (1989), Maccoby and Jacklin (1974), Robert and Bell (2000a), and Sanz de Acedo and Garcia (2003).

One plausible reason that may explain for the absence of gender differences in the spatial ability measures prior to training is that male and female participants involved in the study were of similar academic backgrounds, which may correlate strongly with their spatial abilities. The students selected for the study comprised Form Four secondary school pupils (i.e., tenth graders) taking the engineering drawing subject as one of their technical electives. Only students with good mathematics grades can enroll in these technical courses. This is one of the prerequisites for technical studies as prescribed by the policy of the Malaysian Ministry of Education. Significant relations between mathematics achievements and spatial ability measures have been established in studies suggesting that high spatial individuals are better in mathematics compared to low spatial individuals (Baenninger & Newcombe, 1995; Bektasli, 2005; Ben-Chaim,

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1989). In the same light, Kulp et al (2004) stress that poor visual perceptual ability should be considered to be amongst the skills significantly related to poor mathematics achievement.

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In this study, it is highly probable that there were no superiority in terms of spatial abilities of one gender over the other since both genders were of similar level in mathematics background. Thus, both genders' equivalent achievements in mathematics correspondingly may translate into similar level of spatial ability as confirmed by the statistical analysis based on their differences in means of their spatial pretests. Seen from a wider perspective, this finding may not be unique as gender differences on cognitive and psychosocial tasks are getting smaller and declining as reported in a study by Linn and Hyde (1989). Reinforcing this pattern of declining gender disparities, a critical finding from Hyde's (2005) meta-analyses of related research that focused on the effect size of gender differences attests that males and females are alike on most – but not all – psychological variables.

## 6.4 The Improvement in Spatial Visualization after Spatial Training in the Experimental Research

Comparison of mean differences of spatial visualization before and after spatial training for all groups indicated that the participants had achieved significant gain. Hence, the extent of spatial training improvement in this measure was significant in supporting the research hypothesis for this measure of spatial ability (see Research Hypothesis $H_{ii}$, p.17). In other words, there was an effect of training where participants' spatial visualization ability improved after engaging in solving spatial problems which entails the utilization of this component of spatial ability or skill. Participants made fewer errors in solving spatial visualization tasks as compared to their previous commission of errors indicating that they had gained significant improvement after training that focused on this component of spatial ability. In addition, both female and

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male participants were observed to attain statistically equivalent performance in spatial visualization in this study that further qualifies the extent of improvement in spatial visualization.

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### 6.4.1 The Impact of Training Method in the Improvement of Spatial Visualization in the Experimental Research

Further examination was conducted using the two-way analysis of variance which revealed that there were significant main effects of training condition in spatial training. There were significant differential improvement gains in spatial visualization resulting from spatial training based on the three different conditions. This finding verifies part of the research hypothesis that predicts differential training outcomes in spatial visualization due to the main effects of training method (see Research Hypothesis $H_{iii}$, p. 17). In general, those trained in the first experimental condition (i.e., interaction-enabled desktop virtual environment spatial trainer) achieved highest improvement, followed by the second experimental condition (i.e., animation-enhanced desktop virtual environment spatial trainer), and lowest in the control condition (i.e., conventional training using printed media). This finding was confirmed by post hoc test analysis that revealed the greatest performance difference was between the first experimental group and the control group. The difference in spatial visualization between the first experimental group and the second experimental group was also significant. In addition, the participants in the second experimental group were better than those in the control group indicating that spatial training was less effective when using the conventional method of training.

In solving spatial visualization tasks, the participants in the interaction-enabled trainer were able to interact with the virtual objects representing the objects of interest through the mouse-controlled VRML client interface. Interacting with the objects was through panning, twisting, rolling and zooming in the interactive trainer, giving a

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multiple viewpoint facilitating visual perception and processing of objects in 3D space. These objects could be viewed from close up and from a distance allowing users to examine specific and holistic features of the objects respectively. Effectively, the participants' interactions mimicked physical, real-world actions when one inspects such an arrangement of interconnected objects in the real world that helps facilitate better understanding of spatial relationships and arrangements, in this case, stacks of blocks. The participants could alternately observe the spatial arrangement of the blocks from various views and navigate through the space in an interactive manner. This mode of training was found to be effective in enhancing their spatial visualization skills that concurs with Smith's (2001) study, which suggests that alternating between interactions and observations is the best way to learn spatial visualization. Larger training gain in interaction-enabled trainer in comparison to the other methods could be attributed to the availability of features that encourage users to actively process information (Ali & Ferdig, 2002; Brady, 2004).

The second most effective in spatial visualization training involved the condition of training that was enhanced using animations, which suggests that participants utilizing these features gained better insights and understanding of tasks that demand visual perception and cognitive processing based on spatial visualization. Animations are used to fulfill a cognitive function where in this role they support students' cognitive processes that ultimately result them understanding the subject matter (Love, 2004). The set of spatial tasks designed in this study required participants to solve problems associated with stack configurations composed of regular rectangular block. In determining the correct number of blocks in contact with a target block entailed the participants to mentally visualize all the six faces of a particular block to determine these faces' positions and relations in the 3D space with other faces of neighboring blocks. The animations when activated will cause the actual blocks that were in contact with the target block to change their colors to animated bright colors, thus highlighting their positions in relations to the target block. Each of the blocks will move into space, gradually one at a time, to allow the participants to observe the target block's position in

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space and its relation to the displaced blocks. Effectively, these animations helped in the externalization of the internal visualization process that the participant would invoke in solving these spatial visualization tasks. Apparently, the animations could have functioned as a cognitive tool in problem solving, which over time in training would have helped the participant to develop efficient spatial strategy. Spatial training enhanced with animations seemed to benefit both male and female participants in this study where their performances in this group were equivalent (see Table 5.17 and Figure 5.2). This finding concurs with earlier studies by Klein and Koroghlanian (2004) and (Tversky, Morrison, & Betrancourt, 2002), which if taken together underscores the role of animations in training domains involving complex systems or complex configuration of objects in 3D space. Training method based on printed materials yielded the lowest improvement gain suggesting that this type of medium relying on static images and texts did not provide optimal visual cues and dynamic behaviors that can help in the visualization process for spatial training.

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### 6.4.2 The Impact of Gender in the Improvement in Spatial Visualization Training in the Experimental Research

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The difference in the spatial visualization improvements between female and male participants was found to be non-significant which fails to support the research hypothesis of differential spatial improvements due to gender effect favoring male participants over their female counterparts (see Research Hypothesis $H_{iv}$, p. 15). Descriptive statistics showed that in general male participants outperformed their female counterparts but ensuing inferential statistics revealed that the overall difference was not significant in this study. Interestingly, the analysis of variance showed that there was a significant interaction effect between the spatial training method and gender in the study (see Table 5.18, p. 148). A pattern emerged indicating the convergence and divergence of performance measurements of girls and boys respectively (see Figure 5.3, p. 150). Male participants tended to gain differential level of improvement gain in this

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subset of spatial ability based on the different training conditions compared to their female counterparts. Girls were more likely to improve their spatial visualization irrespective of methods of training they experienced. For boys, spatial training was most effective in the first experimental condition (i.e., interaction-based training) compared to the other groups. However, girls in same group were comparable to the rest in the second experimental and control groups in terms of spatial visualization gains. In fact, when comparing the means of spatial visualization posttest scores, female participants in the interaction-based group attained almost equivalent performance with the female participants in the control group (see Table 5.17 & Figure 5.2, p. 147). This suggests that the high degree of interactivity afforded in the first experimental condition via interaction had benefited male participants more than their female counterparts.

On the other hand, the finding of similar improvements in spatial visualization among females irrespective of the training settings they experienced can be explained from females' psychological backgrounds. Although there were no significant gender differences in spatial visualization prior to training, however, in general males were slightly superior to females in this cognitive ability that might influence the effort they put in the interaction-based training. Heeter (1994) found that, in general, males were more interested in VR learning experiences via interaction more than females. Females had also been found to have problems when manipulating computerized tasks. Similarly, the finding from Ziemek's (2006) study indicates that gender has an influence on how attracted an individual is to electronic games. Three-dimensional (3D) and two-dimensional (2D) electronics games are most appealing to males and females respectively. Observations during training indicated that boys were far more active in exploring the virtual training environment in the interaction-enhanced trainer than girls were that concurs with the previous findings. In addition, comments regarding the application usability (see Table 5.34b, p.172) provide some insights that revealed potential navigational skill differences favoring boys rather than girls making the former less adept in the virtual scene.

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Boys were probably more dexterous in using the mouse-controlled interface to move around in the virtual environment and to interact with the virtual objects. In determining the correct answers to a spatial problem, the participants normally had to examine the block arrangements by moving around in the virtual 3D space through mouse-controlled interface. The effects from these actions engender a sense of translational and rotational movements of objects as perceived by the learners from multiple viewpoints. Following this, they had to make a choice among six (6) alternatives that represents the correct solution. If a wrong answer was made, they could return to the virtual environment to repeat the interactions and exploration and thus experienced new perspective and insights to better understand the task. Repeating this cycle several times serves as an iterative process that might have helped boys train more efficiently in the interaction-based trainer. Premised from the constructivist standpoint, learners would be able to continually construct and refine the correct mental schema of the spatial solutions of the spatial problems. On the other hand, the lack of spatial skills among girls in the same training setting could have resulted in far less engagement in these manipulation and interaction. This in effect would have resulted in less mental manipulation efforts exerted by girls leading to poor mental schema of the spatial solutions as indicated by lack of significant improvement in their spatial visualization after training. This is not surprising in view of individual differences in traits such as spatial ability that is important in determining the usability and acceptability of 3D environments (Modjeska & Chignell, 2002; Steinke, Huk, & Floto, 2003).

Another interesting trend in the interaction between training condition and gender was observed in the control group. Girls in this group exhibited higher spatial visualization ability or skill than their male counterparts after training using printed materials. In fact, male participants in this particular group showed the lowest improvement in spatial visualization among all groups which warrants some explanations to this finding. The conventional training comprised a similar set of spatial exercises similar to the other two methods but was contained in a printed booklet with 2D pictures or diagrams of spatial arrangement of regular blocks in stacked

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configuration. Participants were required to examine these diagrams and choose the correct number of blocks among the six alternatives. They were also supplied with a set of solutions in the form of a booklet showing the exploded views of the target and other blocks to aid comprehension if required. This type of learning or training has been found to advantage male pupils as evidenced from an earlier study by Geiger and Litwiller (2005) who noted that gender differences were found for question answering information from diagrams but not for information derived from text. The finding showing female advantage was quite unexpected that suggests attitudinal rather than cognitive factors may have influenced such an outcome in this study. Specifically, the ability of female participants in this study to train in conventional training method better than males may be influenced partly by motivational factor reflecting differential level of engagement in training.

Girls' higher attitudinal scores (see Table 5.33, p. 169) on perceived training effectiveness and improved cognition for the control group were higher than boys provide some clues to explain why boys fared quite badly. For perceived training effectiveness, girls' rating was almost one and half higher than boys in magnitude. Similarly, for perceived improved spatial cognition, girls' rating was almost double than boys. These large differences did not replicate in the novel training conditions. Thus, one plausible explanation for female higher perception for the conventional condition is that this type of training requires a learning approach that is based on memorization and recall of facts rather than spatial skills favoring verbal over spatial learners (Gurian et al., 2005). In addition, most probably, the boys in this group were not highly motivated in using printed materials supplemented with static pictures that might undermine their effort in training over the long run. According to Bandura (1986), motivation is influential in shaping learners' ability to control their thoughts, feelings, and actions that ultimately exert either a positive or negative impact in their academic endeavors.

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## 6.5 The Improvement in Mental Rotation Accuracy after Spatial Training in the Experimental Research

Comparison of mean differences of mental rotation in terms of accuracy before and after spatial training for all the groups indicated that the participants achieved considerable gain. Hence, the extent of spatial training improvement was significant in supporting part of the research hypothesis for this measure of spatial ability (see Research Hypothesis $H_{ii}$, p. 17). An effect of training was observed where participants' mental rotation accuracy improved significantly after engaging in solving spatial problems that taps on the specific mental processes (i.e., ability to visualize images and rotate them in one's mind). Through constant practice in mental rotation tasks, participants made fewer errors in solving the spatial tasks compared to before training indicating that they had become more efficient by being more accurate. Both female and male participants were also observed to attain statistically equivalent performance in mental rotation in terms of accuracy in this study that further qualifies the extent of mental rotation accuracy training.

### 6.5.1 The Impact of Training Method in the Improvement of Mental Rotation Accuracy in the Experimental Research

Post hoc analysis conducted revealed significant gains in mental rotation accuracy between interaction-enabled condition and conventional method, and between animation-enhanced condition and conventional method. This finding, in effect, partly supports the research hypothesis of spatial ability improvement favoring novel methods over conventional method (see Research Hypothesis $H_{iii}$, p. 17) for this spatial measure. No significant improvement difference was found between interaction-enabled condition and animation-enhanced condition signifying that the effects of interaction and animation in the spatial trainer were equivalent in this study. The lack of evidence to support the assumption of greater advantage of the interaction-based training in the desktop virtual environment trainer over the animation-based training of the same

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trainer means that the effects of interacting with the virtual objects and using animated rotations of the tasks were equally effective in assisting participants to perform the mental rotation tasks in this study. In interaction-enabled trainer, the process of solving the mental rotation tasks typically demands three sequential steps where a learner first needs to view the comparison object on the screen by means of visual perception, then visualizing it in her or his mind, and finally mentally rotating it about imaginary axes until it makes spatial correspondence with the target object (i.e., both the comparison and target objects are in congruence). Clearly, the first step is the most critical stage where the ensuing steps that follow are contingent on this initial step. Thus, improving the skill to solve this type of task entails greater perception of objects from several viewpoints. Interacting with the virtual training objects via the mouse-controlled interface engenders continuously changing viewpoints of the onlooker with respect to the objects. These actions when performed in controlled and judicious manner enable the onlooker to clearly perceive the orientations of the virtual object in relation to its axes. At any time, a learner can stop the interactions allowing she or he to examine the virtual object's orientation in space to form a mental picture and then imagine the rotation from this current view. This constant viewing of the virtual objects from multiple angles helps the learner to predict the resultant position and orientation of objects. From cognitive perspective, these interactions in the virtual environment facilitate better visual perception of virtual objects that subsequently aids the process of visualization and rotation operations.

On the other hand, animations in the desktop virtual environment when used will show the rotations of a comparison object about the axes in 3D space in sequential and paced fashion. Apparently, animations proved to be an effective cognitive tool for participants in solving mental rotation tasks particularly that require more than one rotation to bring the comparison object into the correct orientation that perfectly matches the target object. In addition, this particular outcome highlighting the effectiveness of the animation-enhanced training over conventional training using static pictures concurs with the notion that animation facilitates learning when solving a

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problem necessitating multi-step processes that static graphics do not provide (Tversky, Morrison, & Betrancourt, 2002). The process of solving a complex mental rotation task in this study first demands visualizing and then mentally rotating the comparison object about the proper axes in a step-by-step approach until it perfectly matches the target object. Clearly, the better performance gained during training in this method was the result of the participants utilizing the animations to help them form the correct mental pictures of the objects and the correct steps (i.e., rotations) to arrive at the correct solutions (i.e., orientations). From the cognitive view, animations might have reduced their efforts on constructing mental representations of complex geometric objects that effectively facilitated their overall learning ( Holzinger, Kickmeier-Rust, & Albert, 2008). In other words, animations helped the participants to internalize the correct representations of objects being studied into mental images and then to perform the rotations mentally that were cognitively more difficult when trained using the conventional method.

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### 6.5.2 The Impact of Gender in the Improvement of Mental Rotation Accuracy in the Experimental Research

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Surprisingly, the effect of gender in training did not materialize that led to the conclusion that the extent of gender effect in mental rotation accuracy training was not significant that fails to support the research hypothesis of male advantage over females in this study (see Research Hypothesis $H_{iv}$, p. 17). In other words, there was no evidence to support that a particular gender was more accurate than the other in this particular measure of spatial ability. That this study produced gender parity in mental rotation in accuracy measure after training contradicts findings from previous studies by Hugdahl et al. (2006), and Turos and Ervin (2000) that favored males over females. The fact that participants of both genders gained equivalent improvement after training was unexpected entailing closer examination given that gender differences in mental rotation favoring males have been found to be the most consistent and robust in studies

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of spatial abilities (Linn & Petersen, 1885; Voyer et al,, 1995). One plausible explanation for the absence of differential performance outcomes is that both female and male participants were equivalent in terms of mental rotation at the outset of spatial training. There was no gender group having an advantage over the other group that may exacerbate gender differences in mental rotation after training. Both gender benefited equally from spatial training in mental rotation in the study.

A significant interplay between training method and gender was found suggesting that the effectiveness of training method depended on participants' gender in the study. Male participants that trained in interaction-enabled trainer improved their mental rotation accuracy at higher level compared to girls in this same group. In addition, boys in the interaction-enabled trainer outperformed boys that trained conventionally. However, differential performances among boys in different groups were not replicated by girls. In fact, the overall performances of girls in the three conditions were equivalent in this study. Having the ability to interact with the training objects in the interaction-enabled trainer seems to benefit male participants more since this feature was not available in the control condition. Interacting with the virtual objects by navigating the virtual world enables a learner to examine the comparison object's orientations more clearly from various viewpoints which assists better visualization and mental rotation than static graphics. From the participants' comments regarding perceived improved cognition (see Table 5.34a, p. 171), there were evidence suggesting that some of the participants were able to internalize the spatial configuration and to perform mental rotations of the virtual training objects through constant, interactive practice.

The process of interacting through navigational actions seems to provide a clearer picture of the visual object in space allowing learners to visualize the object with less cognitive effort which consequently facilitates them perform the mental rotation more efficiently. Clearly, this method of training aids the visualization of objects prior to rotational operations in their minds. However, as previously highlighted by Heeter,

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(1994), females' psychological traits such as differential level of interest in which males were more enthusiastic and differential level of appeal favoring males in using learning materials and games based on virtual and 3D environments ( Ziemek, 2006) may partly contribute to the finding that girls did not capitalize much on the virtual training environment. Females' apparent lack of these experiences could have precluded them from exploiting the training benefits in interaction-based trainer; their inability to interact productively were evidenced from the negative comments made by the female participants based on their training experience. Potential differences in mouse and keyboard interaction skills may also partly contribute to this finding where a study by Adamo-Villani, Wilbur, and Wasburn (2008) found that girls completed object manipulation tasks slower in desktop VR compared to boys due to the latter's extensive exposure to such similar environments. Another plausible reason for girls who did not perform at the same level as boys in this training setting could be attributed to gender differences in interaction and navigation skills that might have amplified when using small display devices such as the 15-inch computer monitors used in the study. In a study by Czerwinski, Tan, and Robertson (2002), they found that large display with wider field of view could reduce gender bias in virtual environment navigation. They concluded that users of both gender perceived more information via head/eye movements that are better facilitated in the wide display of virtual environment. Thus, monitors of small screen size used in the study might have limited this visual perception, affecting more on girls than boys.

Equivalent mental rotation improvements were observed between females and males in the animation-enhanced spatial trainer. Girls and boys in this group were both able to train equally well in this method that utilized animations for mental rotation operations. Apparently, animations of rotating objects about the axes in 3D space provided them relevant cognitive cues that improve problem solving of the mental rotation tasks. Having examined the animation of the mental rotation steps for a problem, the participant could internalize the representation of a perceived image accurately and subsequently rotate the image effortlessly. Eventually, with constant

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practice with the help of animations, there would be less cognitive load when they performed these tasks compared to the conventional training benefiting both female and male participants. In addition, animation-based training did not require proficient navigational skills that might have precluded possible gender superiority of one gender over the other that had manifested in the interaction-based trainer.

Differential performance in mental rotation accuracy tasks favoring boys in the interaction-based trainer was found to be reverse in the conventional training group (see Figure 5.5 p. 152). For conventional training, girls outperformed boys suggesting that solving mental rotation tasks through exercises based on printed materials supplemented with static graphics was better carried out more effectively by the former. Just as in the case of boys trained for spatial visualization in conventional method, they were again found to achieve relatively low improvement gain in mental rotation in this training setting. Training in this method comprises printed exercise worksheets containing similar spatial exercises. Solutions to the problems were also included that show the correct rotations by means of static graphic illustrations with textual explanation showing the sequential steps (i.e., rotations) of the comparison objects about the axes to perfectly match the target objects. They could use these graphical solutions during training that helped reinforce their understanding or to guide them in solving the more complex tasks. These graphics helped the participants in such a way that they no longer needed to solve the problems entirely in their minds but could use them to see the step-by-step approach in problem solving. Clearly, performing mental rotation tasks using text and static graphics entails learners to make inferences between these two types of information in coordinated manner.

The presentation of training materials in words and pictures can engage learners to be active in learning through mental connection between pictorial and verbal representations that is viewed to favor males as informed by Geiger and Litwiller's study (2005). However, the opposite was true in this conventional setting where girls achieved better improvement over boys and this unexpected finding could be partly

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explained from motivational factors as evident from the participants' feedback after training. In this study, female participants reported higher ratings for perceived training effectiveness and improved cognition in conventional training compared to males. Though this attitudinal measure was measured based on a self-reported usability questionnaire, nevertheless it provides a vital clue to the level of engagement in training. Girls might be more serious and more engaging in performing mental rotation tasks in this method compared to boys, resulting in better improvement gains of the former. On the other hand, boys might be less motivated and thus less focused in conventional training, resulting in low performance.

## 6.6 The Improvement of Mental Rotation Speed (i.e., Reaction Time) after Spatial Training in the Experimental Research

Overall, there were no significant mental rotation improvements for speed measure for all the three groups based on the comparison of mean differences before and after spatial training. This leads to the conclusion that the effect of training for the improvement in mental rotation speed was quite small to support the research hypothesis of significant improvement for this spatial ability measure (see Research Hypothesis $H_{ii}$, p. 17). In other words, participants' speed or reaction time after training in solving mental rotation tasks did not differ substantially from their prior mental rotation speed measure. Hence, the extent of the effect of training in mental rotation speed or reaction time did not replicate the significant training effects that had been observed for spatial visualization and mental rotation accuracy measures previously discussed. More poignant, the participants' reaction time in solving mental rotation tasks were in fact had increased slightly (i.e., they became slower compared to their earlier performance).

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### 6.6.1 The Impact of the Training Method and Gender in Mental Rotation Speed (i.e., Reaction Time) in the Experimental Research

There were no significant differences in mental rotation speed measure among the three groups based on the different methods of training. Irrespective of the training condition, the participants did not improve significantly by becoming faster compared to their initial reaction times in the mental rotation tasks. This finding effectively fails to support the research hypothesis of differential improvements based on training methods favoring the novel approaches over the conventional method (see Research Hypothesis $H_{iii}$, p. 17). The finding indicates that differential improvement gains attributed to different conditions of training were marginally small to be significant. In addition, there was no significant gender difference after training in the reaction time of mental rotation implying that the extent of gender factor in influencing training outcome was not significant. In this study, both female and male participants were on par in this measure, indicating that neither gender made significant gain by becoming faster after training in mental rotation tasks that effectively fails to support the research hypothesis of significant gender difference favoring boys over girls after training (see Research Hypothesis $H_{iv}$, p. 17)

In contrast to the earlier findings for spatial visualization and mental rotation accuracy measures described above, this particular finding suggests that the types of training used to improve mental rotation reaction times may have little impact. The result of this non-significant improvement in reaction times may be a product of various interactions of psychological and methodological variables affecting the training outcome beyond the control in this study. The finding of no improvement gain in speed factor of mental rotation in this study reflects the traditional assumption in the perception literature that the speed of the imagined rotation is a fixed capability of an individual thus immune from training. This assumption is based on Metzler and Shepard's (1974) study indicating that individuals "can perform the mental rotation at no faster than some limiting rate" (cited in Shepard, & Cooper , 1982). If this holds, it means that the participants in the study were already operating at this optimal level

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where training had little impact for improving speed in mental rotation tasks. However, some researchers had challenged the limiting rate criterion such as Cohen and Blair (1998) who found that mental rotation speed can increase under certain conditions.

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In addition, this result could also be attributed to methodological approach adopted in the study. Time restriction imposed by school administration precluded longer training session. The duration for this experimental study spanned six weeks involving six training sessions distributed evenly, with each session lasting for only two hours that might not be sufficient for the participants to enhance their reaction times. Apparently, to become faster in solving mental rotation tasks may entail greater training exposure by having more practice than previously encountered in this study. Through longer engagement in spatial activities tapping on mental rotation ability may result in learners developing efficient strategy to solve the tasks quicker. Alternatively, a dedicated mental rotation speed training regime can be implemented to help one become quicker in solving mental rotation tasks rather than alternating it with spatial visualization training.

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## 6.7 The Impact of Training Method and Gender on the Performance of Engineering Drawing Task in the Experimental Research

It was observed that there was a main effect of training condition on the performance of basic engineering drawing task. Those trained in the interaction-based trainer were found to outperform the other two groups significantly. On the other hand, there were no significant differences between animation-based training and conventional training groups. The overall performance of those trained in interaction-based trainer was relatively superior than the other participants could be traced to their higher spatial ability gained in training, particularly in spatial visualization, as discussed earlier. This finding lends support to the research hypothesis of a group with higher spatial ability outperforming the other groups of lower spatial ability in solving an engineering drawing task (see Research Hypothesis $H_v$, p. 17). In addition, this finding

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provides evidence to support that that was a training transfer from training domain to engineering drawing task domain.

Also observed was a significant gender difference in the performance of engineering drawing task favoring boys over girls where the former committed less errors compared to the latter. Gender was also found to be an important variable in explaining the variation of engineering drawing task performance in this study. In general, males tended to perform better than females which replicate earlier study by Scales (2000) that focused on gender and technical graphics learning revealing lower final examination grades of females compared to males. This gender difference in the performance could be partly explained by the different levels of spatial ability among males and females. Male participants in this study were found to possess a slight advantage in spatial visualization and mental rotation abilities than their female counterparts that might facilitate better solving of such a task through improved spatial cognition and processing.

Solving an engineering drawing task necessitates an individual to engage in mental processing tapping on spatial visualization suggesting that boys – who are generally regarded to be more spatially skilled than girls – would be in a better position in learning the subject matter (Olkun 2003; Prieto & Velasco, 2004). However, this explanation is not entirely conclusive in explaining the gender difference in engineering drawing performance as other factors such as motivational and attitudinal variables may also come into play further complicating the process of problem solving of the task. Nonetheless, the findings strongly indicate that the participants who had gained higher improvement in spatial ability through interaction-based training and male participants to some extent possessed higher spatial ability that led to better problem solving in spatial tasks that are contingent on this skill.

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## 6.8 Training Transfer from Spatial Training Domain to Engineering Drawing Task Domain in the Experimental Research

This study also examined the impact of spatial visualization and mental rotation of the participants in solving an engineering drawing task through the regression analysis. In addition, the analysis also sought to determine which particular component is most critical and whether gender plays a critical role in the similar task. It was found that almost 60% of the variance in engineering drawing performance was accounted for by the combined effect of spatial visualization and gender. Spatial visualization accounted 51% and gender explained 9% of the performance variance, which supports the last research hypothesis of the study (see Research Hypothesis $H_{vi}$, p. 17). Other measures of spatial ability, namely mental rotation accuracy and mental rotation speed were not significant in the analysis suggesting that their impact in engineering drawing performance were not substantially strong. Hence, spatial visualization was established to be the factor more critical than mental rotation in the performance of basic engineering drawing task. This is hardly surprising given the concept of a quasi-hierarchical relation in the network of the different intellectual capacities as posited by Carroll (1993).

Based on this premise, a spatial visualization test would contain several aptitudes of lower rank, including rotation, despite this ability being a vital aptitude (Carroll, 1993). This means that spatial visualization ability is much more complex than the mental rotation ability where the former will be more engaged by learners in solving an engineering drawing task. The universally adopted convention of engineering drawings comprising drawing of 2D multi-view of orthographic projection and 3D isometric representation entails the visualization of 3D objects and the corresponding mental transformation to 2D representations or vice versa requiring mental operations akin to spatial visualization. This result also replicates previous findings by Olkun (2003), Prieto & Velasco (2004), and Tuan Zaidi (2002) indicating that the ability to solve an engineering or a technical graphic task is dependent on one's level of spatial visualization ability more than mental rotation. These studies suggest that high spatial

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individuals would likely to perform better than low spatial learners. In a similar vein, Potter and Van der Merwe (2001) caution that students with low spatial ability are at risk with regard to passing engineering graphics courses which further highlight the needs to address the issue of spatial visualization training. Engineering drawing or technical graphics is a means of communicating technical ideas using graphical images (Giesecke et al., 2002). Understanding and producing these drawings necessitates engineers and drafters to visualize those graphical images in their minds and perform mental manipulation to understand spatial relationships and layouts of the drawing elements. An adequate level of spatial ability, particularly in spatial visualization, is very much needed to enable students learn the concepts of an engineering drawing or technical graphics effectively.

In tandem with the regression analysis above, comparison of performance score means among the three groups were analyzed through an analysis of variance. Any group differences in the engineering drawing performance can be explained from their differential level of spatial visualization and mental rotation abilities. It gives a measure on the transfer of spatial ability skills acquired from the spatial training to solving an engineering drawing task where a group with better spatial ability will outperform groups of relatively lower spatial ability. The analysis revealed that the performance of the engineering drawing task of the interaction-based training group was higher than the other two groups. The performance of the animation-based training group was slightly higher than the control group, but the difference was not statistically significant. As discussed previously, the interaction-based training group had gained higher spatial ability improvement compared to the animation-based training group and the control group. Juxtaposing the performances of the engineering drawing task and improvements in spatial ability based on the three training conditions revealed that the higher the performance of the task the greater was the spatial ability improvement.

The differential engineering drawing task performances based on the three training conditions provide strong evidence that spatial ability is a detrimental factor

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influencing the ability of participants to solve the task. There was a transfer of these spatial abilities from spatial training to solving an engineering drawing task in particular the spatial visualization. In general, the group of higher spatial ability would outperform the groups of relatively lower spatial ability. From the constructivist learning standpoint, the knowledge constructed during spatial training has been applied into another domain where learners tried to solve the engineering drawing task. In other words, there was a transfer from knowledge construction to knowledge application enabling the participants to apply the knowledge and skills acquired from training to solving the drawing task.

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## 6.9 Overall Findings

Several important findings emerged from the discussion focusing on the research questions that has revealed vital information with regard to spatial ability training. Overall, it has been observed that spatial visualization and mental rotation accuracy can be improved through training but not for mental rotation speed in this study. In addition, training using novel methods in particular the interaction-enabled spatial trainer was more effective than the conventional method. In fact, both the interaction-enabled training and animation-enhanced training conditions were designed utilizing the features of the same spatial trainer. Combining these two conditions will make the spatial trainer a powerful tool in enhancing spatial ability for future study. Specifically, this study has shed some insights concerning spatial training involving spatial visualization and mental rotation which are vital for engineering drawing learning involving Form Four students of a Malaysian secondary school (i.e., 11th. graders) that are elaborated as follows;

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### 6.9.1 Spatial Visualization Training Effectiveness attributed to Training Method and Gender

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Spatial visualization training in the interaction-enabled desktop virtual environment trainer that allows interaction with virtual training objects was the most effective where the participants had made substantial improvement. Interactions with the virtual objects provide better visual perception of spatial arrangements of the spatial visualization tasks that leads to better visualization of the task thus facilitating the ensuing mental manipulation and transformation. Male participants trained better in the interaction-enabled condition compared to females in the same setting where the latter exhibited relatively poor improvement gain in spatial visualization. Lack of prior computer experience and/or computer familiarization coupled with a slight disadvantage in spatial ability might have compromised female participants' performance where training to solve spatial visualization tasks in this study requires a high degree of interaction and navigation. Being relatively disadvantaged in these ability and skills, girls might have not experienced better visual cues and visualization of the task that led to higher cognitive effort to imagine these spatial configurations leading to poor problem solving ability.

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Animation-enhanced training condition in the desktop virtual environment trainer was the second most effective in spatial visualization training. In this study, the participants became more accurate in performing spatial visualization tasks. Animations showing the steps in solving the spatial tasks comprise the motion of virtual blocks detaching from the target block enabling the participants to have better perceptual cues thus improved visualization of the block configuration in their minds. From the cognitive load theory, these animations may have reduced learners' initial effort to visualize the objects being studied especially from the initial stage of training when visualization tasks can be too overwhelming to some who may lack sufficient spatial visualization ability. In contrast to the first experimental condition, both genders in the animation-enhanced training condition gained equivalent spatial visualization improvement. One plausible reason that may explain for the absence of gender

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difference in spatial visualization after training is that training in this setting does not require high degree of interaction and navigation skills that are generally lacking in females. Animations in this type of training can be simply invoked through mouse clicks on the animation button of the interface to let the user to observe the solutions to the spatial tasks, thus relieving them some of the cognitive effort when solving the tasks.

Conventional training had resulted in boys performing poorly than girls in the spatial tasks. An intricate interplay between training condition and gender was detected where boys performed highly when used interaction, moderately when used animations and poorly when used printed materials. Girls on the other hand, performed equally well irrespective of the training conditions they were in. Thus, it could be inferred that for spatial visualization training, interaction-based training favored boy, animation-based training was gender neutral and conventional training disadvantaged boys in this experimental study.

### 6.9.2 Mental Rotation Accuracy Training Effectiveness attributed to Training Method and Gender

Mental rotation training for accuracy measure in the interaction-based condition and animation-based condition were equally effective. Apparently, the ability to interact with virtual objects in the interaction-based condition and to use animations during problem solving in the animation-based condition helped participants train much more effective than those trained using conventional method. In the interaction-based condition, it seems that interacting with the training objects in the trainer enhanced participants' visual perception of the objects thus improving the internalization process (i.e., mental conversion of the perceived objects into mental images in their minds). Consequently, this helped them form accurate mental schema when performing the mental rotation tasks. On the other hand, animations showing the steps in solving the

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mental rotation tasks might have relieved participants of the cognitive effort that they would have to exert themselves during problem solving if such a cognitive tool were unavailable. In addition, animations as a cognitive scaffold could have helped participants form the correct mental schema enabling them to perform the mental rotation tasks more accurate than before training.

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Males trained better in the interaction-based condition compared to females where the latter exhibited relatively poor improvement gain in mental rotation accuracy. Lack of prior computer experience and/or computer familiarization coupled with a slight disadvantage in spatial ability might have compromised females' performance where training to solve mental rotation tasks in this study required a high degree of interaction and navigation. Being relatively inexperienced and/or lacking in these skills, the girls might have not experienced better visual cues and visualization of the task that led to higher cognitive effort to imagine the accurate rotations leading to poor problem solving ability.

Conventional training relying on printed materials consisting of text and static graphics had resulted in less improvement gains in spatial visualization and mental rotation accuracy compared to the novel methods. Spatial training typically deals with interaction and manipulation of objects in space allowing participants to examine the spatial properties and relationships. This method was not effective due to its relatively poor representation of training objects of three-dimensionality to two-dimensional format. The resultant lack of cognitive correspondences between the two formats could hinder visualization of the tasks that consequently produced less accurate mental manipulations. Female participants gained relatively higher improvements in spatial visualization and mental rotation accuracy than male participants did when trained in the conventional method. Motivational factor rather than cognitive factor was a plausible and detrimental factor affecting spatial training involving boys compared to girls. The impact of less motivation might have resulted in less commitment or engagement to follow through the training sessions.

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### 6.9.3 Mental Rotation Speed Training Effectiveness attributed to Training Method and Gender

For mental rotation in terms of speed measure, there were no appreciable improvement gains across all the three conditions of training. Apparently, the training methods used in this study had little impact in making all the participants quicker in solving the mental rotation tasks. Both female and male participants had not become faster in solving mental rotation tasks after training. In addition, the gender difference between the female and male participants was also found to be non-significant after training. To become faster, probably a learner may need more exposure to intensive practice irrespective of the training method employed. Only through longer engagement in training can the participants form the efficient strategy to solve the mental rotation tasks at faster rate.

### 6.9.4 Transfer of Training to solving Basic Engineering Drawing Task

There was a transfer of knowledge or skills associated with spatial visualization and mental rotation to engineering drawing problem solving. In particular, spatial visualization was able to predict engineering drawing performance significantly. This means that individuals with high spatial visualization ability were able to perform better in solving an engineering drawing task compared to those with lower ability of spatial visualization in the study. The performance of the engineering drawing task was also influenced by gender where in general males tended to outperform females. This could be partly attributed to different levels of spatial visualization between the genders favoring boys. Spatial visualization has been recognized as one of the critical cognitive abilities in learning domains such as technical graphics, thus females who are generally disadvantaged in this skill may be susceptible to greater challenges in pursuing such a program.

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## 6.10 Lessons Learned from the Survey and Experimental Research Studies in Engineering Drawing Instructions

The lessons learned from the research undertaken are several folds. First, students' perceived ability (i.e., self-efficacy) to learn engineering drawing was influenced by spatial experience, mathematic achievement and gender. Generally, students with greater spatial experience reported higher perceived ability to learn this course especially involving topics of high spatial contents such as orthographic, isometric and auxiliary views. In general, boys and respondents with higher mathematic achievements tended to report higher perceived ability to learn this subject compared to girls owing to their greater spatial experience which is indicative of higher spatial ability.

Second, spatial ability namely spatial visualization and mental rotation accuracy could be nurtured or trained for improvement, but mental rotation speed had not improve significantly where the participants had not become faster after training. In addition, the lesson learned from the study is that training in spatial ability using novel methods such as the interactive desktop virtual environment trainer may be mediated by learners' background and gender. In the experimental study, interaction-based spatial training in the desktop virtual environment trainer has been demonstrated to be more effective for a particular gender favoring male participants compared to the opposite gender. Animation-based spatial training seemed to be gender-neutral where both genders benefited equally well in this setting. On the other hand, conventional training seemed to disadvantage boys compared to girls.

Third, it has been established in this study that there was a training transfer from the domain of training to the domain of engineering drawing task. Arguably, the mental processes induced during spatial training were the same cognitive processes invoked in solving engineering drawing task. In addition, among the spatial ability measures examined, only spatial visualization was found to be strongly predictive in accounting for the variance in the engineering drawing task performance. Other spatial measures were not significant to account for the performance variance in the subject matter.

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Hence, the training transfer was attributed to spatial visualization rather than mental rotation. This particular finding underscores the importance of spatial training in spatial visualization to improve students of low spatial ability, which can carry over to learning the engineering drawing in schools.

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## 6.11 Research Contributions

There are several important lessons learned from the research that contribute to further enriching the body of knowledge in visio-spatial, spatial training and engineering graphics disciplines that are interrelated. Some of the findings are not only informative but also important to practitioners in technical graphics, namely students, educators (i.e., teachers or instructors), and school administrators, policy makers, and instructional designers and developers. The contributions derived from the dissertation are centered on the amenability and training of spatial ability, design process guidelines for developing a spatial trainer, and influential factors in the teaching and learning of engineering drawing at the foundational year.

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### 6.11.1 The Amenability of Spatial Ability through Training

Spatial ability is now gaining serious attention by many researchers given its importance in learning domains such as science, engineering, and technology-related disciplines. Its positive impact is also acknowledged in sports where success in related fields is reliant on well-developed spatial skills. Even in mundane life, spatial ability is vital for humans to function safely and efficiently like driving to work or arranging furniture in a house. This ability was earlier conceptualized to be innate thus immune to training and gender stereotyping favoring males was quite evident in earlier literature. However, over the last few decades research has shown that spatial ability can be

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trained and improved, and gender gap is gradually diminishing through training. Albeit the encouraging findings, many researchers believe that the extent of spatial ability improvement is influenced by socio-cultural and experiential factors. The former is gaining prominence as today's societies are becoming more pluralistic bringing in diversity into the students population. Similarly, the latter is also important in that students are also different in terms of prior knowledge and skills when they enter school where some may have engaged in certain activities that had nurtured their ability while some may lack such experiences. In addition, given the multi-dimension nature of this non-unitary ability an improvement in one spatial construct such as spatial visualization may not necessarily be accompanied by similar gain in another dimension such as mental rotation. Thus, spatial training effort needs to focus on individual components of spatial ability rather than generic abilities. Various spatial training methods or conditions have been researched that resulted in mixed outcomes. The findings from the research suggest that the effectiveness of spatial training is heavily influenced by participants' demographics, methodological and technical aspects.

This research demonstrates that spatial ability in general is not immutable but amenable. In particular, the research undertaken provides strong evidence that spatial visualization and mental rotation accuracy can be enhanced through proper training. However, significant improvement in mental rotation speed did not materialize in this study suggesting that to become fast problem solvers in mental rotation may require longer practice duration and/or different methodological training method. This research also demonstrates that both genders benefited from spatial training where differences in spatial visualization and mental rotation accuracy gains between girls and boys were not significant. This particular finding is very encouraging that further adds credence to claims that both sexes are equal in terms of their overall spatial ability that can dispel unfair stereotyping that can disadvantage females in many educational and job sectors.

A very salient finding has been found in this study where there were differential outcomes of spatial training resulting from the interplay between training condition and

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gender. Apparently, male participants tended to train differently when using different methods of training whereas female participants were more or less trained almost equally regardless the training conditions employed. Particularly, this finding suggests that training in spatial ability using novel methods such as the desktop virtual environment spatial trainer may be mediated by learners' background and gender. In addition, other socio-cultural and experiential factors such as age, domain experience, spatial experience, and computer experience may also influence training in virtual environment.

In this study, interaction-based spatial training in the desktop virtual environment trainer has been demonstrated to be more effective for a particular gender favoring male participants compared to the opposite gender. Female participants did not show any significant differential performances in spatial ability measures based on the three training methods they received. The impact of this finding should inform educational practitioners on the needs to be selective and careful in using methods or approaches for spatial training to cater different categories of learners. This is particularly vital when employing 3D virtual environment as a training setting where the efficacy of such a novel tool can be mediated by a host of learner characteristics where in this research gender and spatial ability of students were found to be contributing factors for training effectiveness.

Further research should be conducted to investigate why computer-mediated spatial training is more favorable to boys than girls. In general, the literature on the computer-mediated training in a variety of domains has reported gender differences favoring males over females. The former seems to adapt well in the computerized environment due to their relatively greater level of experience in computer-based activities and games, which are predominantly stereotyped as male domains. On the other hand, girls are usually engaged in activities deemed feminine, which are devoid of or lacking in spatial components thus depriving them the opportunity to enhance their spatial skills. Thus, experiential factor could be one of the aspects that may undermine

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females' readiness and engagement in this type of training. Hence, they may require greater duration of training to get accustomed and familiarized with the novel environment.

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This particular finding also highlights some features of the desktop virtual environment spatial trainer that can be tapped for spatial visualization and mental rotation training. In this study, features or capabilities of the desktop virtual environment trainer namely interaction and animation had been investigated as two separate elements revealing strong training potentials. In the desktop virtual environment trainer that allowed interaction, the participants were able to manipulate the view points of the training objects through the mouse-controlled interface inducing a sense of interaction with the training objects. This helped in greater visual perception of the training objects leading to better mental manipulation particularly for tasks entailing spatial visualization ability. On the other hand, animations helped in the process of problem solving where steps in performing the spatial tasks were broken down in smaller and manageable parts that reduce the cognitive load of learners.

Combining these two capabilities in the desktop virtual environment spatial trainer can be a very powerful feature in spatial training. However, the use of these features must be carefully crafted and utilized judiciously in training applications that should be grounded on sound conceptual framework in order for them be efficacious rather than becoming spurious and distracting elements. In the research undertaken, the amenability of spatial ability, namely spatial visualization and mental rotation accuracy was observed (i.e., spatial ability can be trained for improvement); spatial training also had benefited both genders, but there was an interaction between gender and training condition that produced differential outcomes. Overall, the lessons learned from this study can further enrich the literature with regard to spatial cognition and reasoning that can help inform researchers, practitioners and training application developers for future work and study.

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### 6.11.2 Design Process Guidelines for Spatial Training Application

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The lessons learned from this experimental research using a spatial trainer based on the desktop virtual environment are very informative and useful that can help inform designers and developers regarding important rationales, aspects, and steps needed to develop such training application or tool. It has been demonstrated that such a trainer engenders benefits in spatial training but the effectiveness of the trainer can also be influenced by other factors associated with users' experience and demographic. The rationale for having a tool or application to train learners in spatial tasks has been established in this research in that spatial ability is an important construct of human cognitive functioning. It is not immutable, thus it can be nurtured either directly or indirectly through activities that one engaged in. However, a direct, focused spatial training program is needed in order to achieve greater training effectiveness to justify the effort, time and cost incurred when developing such an application. Failing to develop a well-designed trainer may cause the learners to achieve only generic skill, at best or gain spurious skills, at worst.

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Therefore, the design and development of such a trainer will have to strictly follow a set of rules or guidelines that can help build an effective application or program in spatial training. There are some existing instructional guidelines for developing courseware in many areas of training, however most of them are applicable for school curriculum namely for science, technology, and mathematics courses. A desktop virtual environment trainer has been developed by the researcher for the experimental research that was used to train a number of secondary school pupils in spatial ability namely spatial visualization and mental rotation that are very important for learning subject matters that hinge on visio-spatial comprehension. The researcher had conceptualized and used several design steps to help develop the spatial trainer in

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the study based on the review of current literature pertaining to cognitive, psychometric-testing, digital technology and learning theory.

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### 6.11.2.1 Determining the Specific Training in Spatial Ability

The first step involves identifying the specific components of spatial ability that are required for training. This is important given the multi-facet nature of spatial ability consisting of several distinct but overlapping components. Failure to address this step may risk successful outcomes of spatial training as the training activities will be too generic rather than specific. This first stage is essential as it paves the way for instructional designers to search appropriate learning or training objects to be used by learners as required in the ensuing steps. As demonstrated in this study, training spatial visualization and mental rotation will entail specific objects that are not only unique but efficacious in enhancing the intended skills or ability.

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### 6.11.2.2 Selecting Appropriate Training Objects for Spatial Training

In the experimental research, the selection of objects for spatial training involved examining the literature on psychometric testing of spatial aptitude or cognition. There are a range of test batteries for spatial ability namely mental rotation, spatial orientation, spatial perception, spatial visualization and mental rotation. Many tests are used for the particular spatial components that have high reliability and validity. Thus, using the test items as objects for spatial training will ensure spatial activities or tasks carried out by learners will tap on the precise mental reasoning for the construct to be trained or learned. This strategy of selecting training objects is not only reliable in terms of construct validity but this approach can save time as developing

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training objects from scratch without referencing to earlier works is time consuming and risk using inappropriate training materials.

The efficacy of the proposed trainer will rely on using appropriate training objects that can be designed and developed for learners to use them effectively capitalizing on the cognitive affordances inherent in them. Engaging the objects in training through interaction, animation or manipulation will invoke appropriate cognitive processes in solving the spatial tasks making learners more proficient and skilful in a specific domain. In this research, the training objects for spatial visualization were 3D blocks configured in stacks where through interaction the learners were be able to closely see and visualize various faces of a block in contact with other faces of the neighboring blocks. For mental rotation tasks, two identical 3D objects where one (i.e., comparison object) was displaced at some orientations with respect to the other (i.e., target object). Through interaction, the learners could see and visualize the positions and orientations of the comparison object in relation to the target object that helped in solving the tasks. Thus, selecting appropriate objects for training is vital to ensure learners can utilize them effectively as these objects will serve as a cognitive tool that facilitates thinking during problem solving.

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### 6.11.2.3 Developing Appropriate Instructional Approach for Spatial Training

The third step in developing the spatial trainer is a very critical stage in determining the appropriate instructional and/or pedagogical approach to be employed in training. Identifying the proper instructional training setting at this stage will require an understanding of current theory of learning. There are several learning theories having numerous variants, but essentially they can be categorized along a continuum of two opposite poles namely *instructivist* and *constructivist* perspectives. Experience gained from the research suggests using a mix of the two paradigms where the former can help develop focused training activities through clear training goals and instructions while

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the latter can help learners in knowledge construction through active participation in the training process. The researcher proposes the steps to be followed at this stage involving the development of instructions, organization of training units and sequence of training tasks as explained below.

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i. Developing clear and precise instructions to be followed by the learners prior to engaging spatial exercises will entail communicating and explaining the training objectives that learners should focus on in order to achieve those goals after the completion of spatial training. Having a clear understanding of what learners are expected to achieve after training will help them concentrate on the spatial tasks to be solved.

ii. Organizing the training objects into training units with appropriate instructions that are structured and ordered will need careful analysis of the spatial tasks in terms of the level of difficulty. Then, questions should be crafted carefully that ask learners to derive the solutions associated with spatial tasks that are based on the use of the training objects. Ideally, training units or modules should be categorized into simple, moderate and complex spatial tasks.

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iii. Sequencing the spatial tasks in spatial training will entail putting the simple tasks first, followed by the moderate tasks and finally ending with the complex tasks. The duration of the spatial training for each task will not normally be the same as the degree of difficulty is the not similar for all tasks. Some spatial training may need more time to practice particularly for tasks where performance measures are not only based on accuracy but also speed or reaction time in solving the spatial problems.

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### 6.11.2.4 Developing Appropriate Environment for Spatial Training

The fourth step in the design process of the spatial trainer entails the creation of an environment for spatial training that can transform the spatial tasks containing training objects into an efficacious and convenient form or platform. There are important technological and financial considerations at this stage as developing a particular training environment needs to intricately balance these two main factors especially when involves training application for schools. The level of sophistication of training application will invariably rely on the costs of procurement and ownership that can be prohibitive for implementation in most schools. The experimental research of this study demonstrates that even a low cost training application can be effective for spatial training that is applicable in school context. The platform used in this research is based on a desktop virtual environment where training objects were represented by 3D virtual objects and all instructional information was in textual form. The effectiveness of any training application is not entirely dependent on the degree of technology wizardry but instructional strategy and method do play a crucial role in training.

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### 6.11.2.5 Establishing the Level of Sophistication of the Training Environment

Three aspects that can help a training application developer to select an appropriate training platform as learned from the study are the adoption of authoring or development tools, time to develop the application, and training to use the application by the intended users. Experience from the experimental research suggests that the use of non-immersive VR technology such as desktop virtual environment using VRML-coded training objects is within the reach of many school-based developers due to its low cost of ownership. The development time to develop the training objects and environment will not be too laborious due to the simple system architecture for such implementation. Training or learning curve to use such an application is not steep as desktop computing skills of most secondary school pupils can be transferred into the

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desktop training environment eliminating any specialized training normally inherent in many immersive VR technologies.

For spatial training to be highly effective the correspondence of the virtual training objects and environment should be as close as possible to the real life situation. The higher the correspondence between the digital and actual environments the better it is for spatial training. Several technological aspects that are important to address this requirement are the levels of immersion, interaction or navigation, and realism. Each of the three aspects lies on a continuum of a dimension between low and high extremes. The combination of the three dimensions will engender a sense of presence for learners when they use such a training environment. Higher sense of presence will engage learners to train more effectively and satisfactorily. The level of immersion is typically low in desktop VR and very high in immersive VR that are associated with special data gloves and head-mounted gear. Interaction in a virtual environment ranges from simple navigation using the desktop mouse to highly complex navigation using gestural- and voice-based inputs. The level of realism of the virtual artifacts and environment can be programmed to low level using shaded objects or to high level based on realistic object representation using rendering technique. Thus these factors need to be considered when creating such a training environment not only from technological standpoint but financial as well.

The design process guidelines that have been deliberated are summarized in the Table 6.1a and Table 6.1b on the following two pages that can be used to guide a developer in the design and development of a spatial trainer for spatial ability training.

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Table 6.1a

*Design process guidelines for the development of a spatial trainer (part A)*

| Step | Design process | Guidelines |
|---|---|---|
| 1 | Determining the specific training in spatial ability | In general, there are three (3) sub-skills or dimensions of spatial ability namely spatial visualization, mental rotation and spatial perception. Identify the specific components of spatial ability that are required for training to avoid gaining generic rather than specific effects in training. |
| 2 | Selecting appropriate training objects for spatial training | Review the visio-spatial literature particularly on spatial testing where items in the tests can serve as the focal point in creating training objects, however, ensure that there are evidence to support that the test items are valid and reliable. Training objects to be selected must allow interaction, animation or manipulation to invoke appropriate cognitive processes in solving the spatial tasks.<br><br>Some examples that have been used in the research are;<br>i. For spatial visualization, the training objects consisted of 3D blocks configured in stacks and a learner is required to visualize various faces of a target block in contact with other faces of neighboring blocks.<br>ii. For mental rotation tasks, two identical 3D objects where one (i.e., comparison object) was displaced at some orientations in relation to the other object (i.e., target object). A leaner needs to mentally rotate the former until it corresponds with the latter. |
| 3 | Developing appropriate instructional approach for spatial training | Review the current literature on learning theories and search for evidence from case studies. A mix of *instructivist* and *constructivist* approaches is recommended rather than subscribing to one particular perspective.<br>Three steps should be followed namely;<br>i. Develop clear and precise instructions,<br>ii. Organize the training objects into training units with appropriate instructions,<br>iii. Sequence the spatial tasks in appropriate and hierarchical order. |

Table 6.1b
*Design process guidelines for the development of a spatial trainer (part B)*

| Step | Design process | Guidelines |
|---|---|---|
| 4 | Developing appropriate environment for spatial training | Transforming the training objects and instructional activities into an environment that is efficacious and convenient is very important and this relies on both technological and financial considerations particularly for school application developer.<br><br>Three factors must be considered namely;<br>i. Adoption of authoring/development tools,<br>ii. Time to develop the training application,<br>iii. Training/learning curve in using the application. |
| 5 | Establishing the level of sophistication of the training environment | Training effectiveness in the virtual environment is also influenced by the sense of presence when learners are engaged in training.<br><br>Three factors that should be considered are;<br>i. Navigation/interaction (ranged from mouse-controlled to gestural-,voice-, and tactile-controlled)<br>ii. Immersion (ranged from non-immersive to fully-immersive)<br>iii. Realism (ranged from shaded to rendered) |

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### 6.11.3 Influential Factors in Learning Engineering Drawing

The findings of the survey and experimental research not only demonstrate but further reinforce the important role of spatial ability in successful learning of engineering drawing. Though this dissertation only focuses on the performance of orthographic and isometric views and not on the entire curriculum at the foundational year, nonetheless these two topics represent the core of engineering drawing or principles of technical graphics. The remaining topics are also related with these principles which together form the overall body of knowledge in the subject matter.

Findings from the survey research showed that students' perceived ability (i.e., self-efficacy) to learn engineering drawing was influenced by their spatial experience, mathematic achievement and gender. Generally, students with greater spatial experience reported higher perceived ability to learn this course especially involving topics of high spatial contents such as orthographic and isometric views. In general, boys and respondents with higher mathematic achievements tended to report higher perceived ability to learn this subject compared to girls owing to their greater spatial experience. Spatial experience is indicative on one's level of spatial ability since this type of experience deals with activities engaged by individuals that effectively develops and enhances her or his spatial ability such as mental rotation and spatial visualization. Thus, it can be inferred that students of high spatial ability will be able to follow the course with more confidence since their perceived ability to learn is generally high.

It has been established in this study that there was a training transfer from the domain of training to the domain of engineering drawing task. Arguably, the mental processes induced during spatial training were identical or similar to the cognitive processes invoked in solving the engineering drawing task. Taking cognizance of this contention, there seemed to be a transfer from knowledge construction that materialized during spatial training to knowledge application that happened during solving the engineering drawing task. However, among the spatial ability measures, only spatial visualization was strongly predictive in accounting for the variance in the engineering drawing task performance. Other measures of spatial ability namely mental rotation

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accuracy and mental rotation speed were not significant in the analysis suggesting that their impact in engineering drawing performance were not substantially strong. Hence, spatial visualization was established as the factor more critical than mental rotation in the performance of basic engineering drawing task. This is not surprising given the concept of a quasi-hierarchical relation in the network of the different intellectual capacities expounded by Carroll (1993).

Based on this premise, a spatial visualization test would contain several aptitudes of lower rank, including rotation, despite this ability being a vital aptitude Carroll (1993). This means that spatial visualization ability is much more complex than the mental rotation ability where the former will be more engaged by learners in solving an engineering drawing task. The universally adopted convention of engineering drawings by the industries basically consist of 2D multi-view drawings based on orthographic projection supplemented with 3D isometric representations entails well developed spatial visualization in order to produce the drawings or to interpret such drawings. Different forms of visualization occur between the two processes involved in the production and interpretation of engineering drawing. Representing a three-dimensional object on a two-dimensional plane surface is contemplated by a draught man while an engineer must create a three-dimensional object by working from the two-dimensional representation of the object. The second perceptual processing is more difficult because the integration of a number of different views into a single spatial image relies on the correct reading of the views. Thus, the ability to visualize the relationship between the two-dimensional and three-dimensional characteristics of an object plays the central role in engineering drawing instructions.

In addition, a small but significant relationship between gender and performance in engineering drawing task was also found indicating that, in general, male participants outperformed their opposite counterparts. This finding runs parallel with earlier findings that indicate strong association between performance in engineering drawing or technical graphics and gender where male advantage is linked to males having relatively superior spatial ability particularly spatial visualization. Like in any major countries, majority of the topics in the foundational engineering drawing curriculum in Malaysian

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secondary schools are infused with spatial contents entailing greater degree of spatial cognitive effort to learn. Arguably, the higher the level of one's spatial visualization the higher his or her ability to follow the course with ease and confidence.

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The impact of this finding should inform engineering drawing instructors that students ability to learn the subject matter is dependent on students' spatial ability particularly spatial visualization which can be diverse in the students population. This sub-component of spatial ability should be treated as a prerequisite for learning engineering drawing or technical graphics that must be identified at the beginning of the lessons. Students enrolled in this course should be gauged for their level of spatial visualization to determine potential problems that may manifest in ensuing lessons. Those identified as having inferior or impaired spatial visualization ability should be given remedial or interventional program. As demonstrated in this study, spatial visualization is modifiable especially among secondary school pupils that helped them improve this ability after training in several conditions. Of interest, is the carefully designed instructional training activities delivered through a three-dimensional computer-generated environment via the desktop platform that was observed to be most effective in spatial visualization training.

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The use of the virtual reality approach in this study has been successful by taking cognizance of the recommendation by Song and Lee (2002) with regard to the application of virtual reality in training that particularly requires a high degree of visualization where training effectiveness can be enhanced through the support of interaction as recommended by Schwienhorst (2002) during the training process. Through greater training exposure in an interactive and experiential setting, learners particularly females and those with low spatial ability may be able to enhance their spatial skills that help facilitate better comprehension of the subject matter. The following four tables: Table 6.2a, Table 6.2b, Table 6.2c and Table 6.2d highlight the instructional issues and challenges, recommended strategy and intervention for instructors and teachers in the teaching and learning process of the subject matter that may be useful based on the synthesis of the findings derived from both the survey and experimental research.

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Table 6.2b

*Instructional issues pertaining to foundational engineering drawing learning and teaching of units 5 to 6*

| Unit | Title of unit | Spatial loading | Self-efficacy in learning the topic | Potential risks faced by pupils | Instructional strategy and intervention to minimize risks |
|---|---|---|---|---|---|
| 5 | Oblique views | Moderate | Moderate | Moderate as learning the contents entails pupils to draw simple to moderate 3D objects using the cabinet and cavalier methods. Most pupils will be able to learn the topic without problem. | Instructional activities through explanation of facts and examples followed with individual exercises are appropriate to use in teaching the topic. Close monitoring and immediate teacher feedback are essential. |
| 6 | Isometric drawing | High | Low | Between moderate and high as learning the contents entails pupils to represent 3D objects on isometric planes. Low spatial and female pupils may encounter difficulty with this topic that entails a high degree of spatial comprehension. | This topic entails instructional activities that foster spatial comprehension through greater student engagement requiring more and/or longer practice sessions. Close monitoring and immediate teacher feedback are essential especially for high risk group. Individualized teaching or group teaching may be required for certain individuals or group respectively. Spatial training to improve spatial visualization can be carried out outside normal school hours. |

Table 6.2c

*Instructional issues pertaining to foundational engineering drawing learning and teaching of units 7 and 8*

| Unit | Title of unit | Spatial loading | Self-efficacy in learning the topic | Potential risks faced by pupils | Instructional strategy and intervention to minimize risks |
|---|---|---|---|---|---|
| 7 | Orthographic drawing | High | Low | High as learning the contents entails pupils to draw 2D views of a 3D object on three principle planes.<br>Low spatial and female pupils may encounter difficulty with this topic that entails a high degree of spatial comprehension. | This topic entails instructional activities that foster spatial comprehension through greater student engagement requiring more and/or longer practice sessions.<br>Close monitoring and immediate teacher feedback are essential especially for high risk group.<br>Individualized teaching or group teaching may be required for certain individuals or group respectively.<br>Spatial training to improve spatial visualization can be carried out outside normal school hours. |
| 8 | Computer Aided Design (I) | Moderate | Moderate | Between low and moderate as learning the contents involves pupils to master the drawing commands of the drafting software to draw simple 2D shapes.<br>Generally, all pupils will be able to learn this topic although initial problems may arise when they first use the unfamiliar digital environment to produce drawings. | The topic introduces pupils to digital environment using a CAD package where ability to learn is partly attributed to familiarization in using a computer system.<br>Less computer experience pupils may need more practice than those with high computer experience. |

Table 6.2d

*Instructional issues pertaining to foundational engineering drawing learning and teaching of unit 9*

| Unit | Title of unit | Spatial loading | Self-efficacy in learning the topic | Potential risks faced by pupils | Instructional strategy and intervention to minimize risks |
|---|---|---|---|---|---|
| 9 | Auxiliary views | High | Low | High as learning the contents entails pupils to draw views of a 3D object that are projected on auxiliary planes.<br>Pupils of low spatial ability and females may encounter difficulty with this topic that entails a high degree of spatial comprehension. | This topic entails instructional activities that foster spatial comprehension through greater student engagement requiring more and/or longer practice sessions.<br>Close monitoring and immediate teacher feedback are essential especially for high risk group.<br>Individualized teaching or group teaching may be required for certain individuals or group respectively.<br>Spatial training to improve spatial visualization can be carried out outside normal school hours. |

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## 6.12 Future Research

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Several suggestions are put forward in this section to allow further improvement on both the methodological and technical aspects for future study. This study was conducted based on the experimental design paradigm to seek new information and insights pertaining to spatial training in multi-facet spatial ability namely spatial visualization and mental rotation that are vital to all in particular students taking technical courses. Some constraints were inevitable in conducting the study due several restrictions imposed by the school administration resulting in the experimental study being conducted in tight setting in terms of time and logistics. Followings are the recommendations proposed for future research in this area to ensure findings of study will be more robust to allow generalization to the student population.

The duration of future experiments should be longer than the present study that only lasted for six weeks. Alternatively, the length of training session per week can be extended longer than the present study which was based on two hours for each session. This should allow greater training practice that may produce different training outcomes compared to the present study especially for speed measure. Previously, no significant improvement in speed for mental rotation was found which entails putting greater focus in this ability in future research. Future study should implement more training practice to examine whether this will improve speed of mental rotation or not. In addition, comparison can be made to determine whether longer training sessions would have a positive effect in mitigating or eliminating gender differences.

Ideally, the screen monitor should be comfortably large enough to allow participants a wider field of view that aid in navigating and interacting in the virtual environment. The use of school computer lab in the present study comprising only small color monitors may not be optimal for viewing and interacting purposes. Studies have shown that gender differences can be eliminated when large display devices are used in



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virtual environment setting. The fact that boys more than girls were more adaptable to computerized environment in this study may also be attributed to navigational skills. Using these two variables i.e., level of navigational skills and size of monitor screen in future experiments may shed some lights regarding training effectiveness in desktop virtual environment based on gender.

The combined effect of interactions and animations should be explored in future study to examine their impact in spatial training. This study had only investigated the separate effects of interactions and animations showing some benefits in using both features in the desktop virtual environment. It will be interesting to study whether there would be significant performance improvement in spatial visualization and/or mental rotation when combined use of interactions and animations is utilized compared to the present experimental study. Comparison of future findings from training settings using interactions, and animations, and combination of interactions and animations can provide greater depth in explaining the training benefits of desktop virtual environment in spatial measures. Lessons from future study can help inform instructional designers to include appropriate elements or features in the desktop virtual environment for spatial training.

The sample used in this study was not large prohibiting the generalization of the findings to the general population. In addition, the participants were Form Four students (i.e., 11th graders) enrolled in technical education in the mainstream secondary schools that may not be representative of the student population throughout the country. Future study should include wider representation of students to cater more diversity based on educational background, ethnicity, and age. Future findings can further add more insights and knowledge concerning the impact of spatial ability in the learning of other important educational fields in the curricula of Malaysian secondary schools that stress on higher order thinking skills which include spatial ability.

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Improvement on mental rotation speed training can be investigated by adopting timed-emphasis strategy when solving the mental rotation tasks. Some studies in mental rotation have shown that gender differences in mental rotation tests can be detected only when explicit instructions emphasizing on time to complete the tests were given to test takers. The methodological training aspects can be improved following along this line of argument by implementing some sort of temporal cues to learners when using the training application indicating whether they are too slow when solving such a task. Such an undertaking can investigate whether there would be substantial differences in reaction time when learners operate in two different setting; one with time emphasis and the other without the temporal constraints.

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# APPENDICES

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## Appendix 1.0: Letter to EPRD

Borang BPPDP 1

Pengarah
Bahagian Perancangan dan Penyelidikan Dasar Pendidikan
Kementerian Pendidikan
Paras 2, 3 & 5 Blok J
Pusat Bandar Damansara
50604 Kuala Lumpur

Permohonan Untuk Menjalankan Penyelidikan Di Sekolah-Sekolah, Maktab-Maktab Perguruan, Jabatan-Jabatan Pendidikan dan Bahagian-Bahagian di Bawah Kementerian Pendidikan

**Bahagian A: Butir-Butir Diri Penyelidik (Untuk *diisi oleh pemohon*)**

1. Nama Penyelidik * (Encik/Puan/Cik) Khairul Anuar bin Samsudin
2. No. Kad Pengenalan: 600210-08-6025
3. Alamat surat menyurat:

   Fakulti Teknologi Maklumat & Komunikasi
   Universiti Pendidikan Sultan Idris
   35900 Tanjong Malim Perak
   No. Telefon: 05-4506000 ext 6415

4. Pekerjaan & Alamat Tempat Bekerja: Pensyarah
   * (Untuk mereka yang bekerja)

**Bahagian B: Maklumat mengenai institusi tempat anda belajar/bekerja**

5. Nama Institusi: Universiti Pendidikan Sultan Idris
6. Alamat Institusi: 35900 Tanjong Malim, Perak
7. No. Telefon: 05-450600
8. Fakulti / Jabatan / Tahun Pengajian: Fakulti Teknologi Maklumat & Komunikasi

**Bahagian C: Maklumat Mengenai Penyelidikan**

9. Tajuk Penyelidikan:

   **Enhancing Spatial Ability in an Interactive Desktop Virtual Environment Spatial Trainer (iDVEST): Its impact on Basic Engineering Drawing Performance .**

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# Appendix 2.0: Approval Letter from EPRD

KEMENTERIAN PELAJARAN MALAYSIA
BAHAGIAN PERANCANGAN DAN PENYELIDIKAN DASAR PENDIDIKAN
BLOK E1 & E2, PARCEL E
PUSAT PENTADBIRAN KERAJAAN PERSEKUTUAN
62604 PUTRAJAYA
MALAYSIA

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**Rujukan Kami :** KP(BPPDP) 603/5 Jld.8 (143)
**Tarikh :** 13 Ogos 2004

En. Khairul Anuar bin Samsudin
34, Taman Anson,
Jalan Ketoyong,
35900 Tanjong Malim,
Perak.

Tuan/Puan,

***Kebenaran Untuk Menjalankan Kajian Di Sekolah, Maktab Perguruan, Universiti, Jabatan Pendidikan Negeri Dan Bahagian-Bahagian Di Bawah Kementerian Pendidikan Malaysia***

Adalah saya dengan hormatnya diarah memaklumkan bahawa permohonan tuan/puan untuk menjalankan kajian bertajuk:

**" Enhancing Students' Spatial Ability Through Constructivist WEB-Based Virtual Environment To Facilitate Learning Of Engineering Drawing Fundamentals "** diluluskan.

2. Kelulusan ini adalah berdasarkan kepada cadangan penyelidikan dan instrumen kajian yang tuan/puan kemukakan ke Bahagian ini. **Kebenaran bagi menggunakan sampel kajian perlu diperolehi daripada Ketua Bahagian/Pengarah Pendidikan Negeri yang berkenaan.**

3. Sila tuan/puan kemukakan ke Bahagian ini senaskah laporan kajian setelah selesai kelak. Sayugia dimaklumkan, tuan/puan hendaklah mendapat kebenaran daripada Bahagian ini jika dapatan kajian tersebut hendak diumumkan kepada media massa.

Sekian Terima Kasih.

**"BERKHIDMAT UNTUK NEGARA"**

Saya yang menurut perintah,

**( Dr. AMIR BIN SALLEH @ MOHD SALEH)**
Timbalan Pengarah,Sektor Penyelidikan Dasar,
Bahagian Perancangan dan Penyelidikan Dasar Pendidikan,
Kementerian Pelajaran Malaysia.

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## Appendix 3.0: Letter to a State Educational Department

22hb.Sept. 2004

Kepada,

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Pengarah
Jabatan Pendidikan Negeri Perak
Jalan Tun Abdul Razak
30640 Ipoh, Perak Darul Ridzuan
u/p: Unit Perkhidmatan Pendaftaran dan Pendidikan Swasta

Yg. Berbahagia Dato',

**Permohonan untuk kelulusan menjalankan tinjauan di sekolah-sekolah menengah yang terlibat dengan pengajaran matapelajaran Lukisan Kejuruteraan di Negeri Perak.**

Adalah saya dengan segala hormatnya merujuk kepada perkara di atas.

2. Untuk makluman Yg. Berbahagia Dato' saya adalah seorang pensyarah di Fakulti Teknologi Maklumat, UPSI yang akan menjalankan penyelidikan berkaitan dengan pengajaran matapelajaran Lukisan Kejuruteraan. Terlebih dahulu saya telah pun memajukan permohonan kepada Bahagian Perancangan dan Penyelidikan Dasar Pendidikan (BPPDP) dan telah diberikan kelulusan seperti dalam salinan surat pihak BPPDP seperti yang dilampirkan [KP(BPPDP)603/5 Jld.8(143)]

3. Sehubungan dengan perkara ini saya ingin memohon kelulusan dari pihak Yg. Berbahagia Dato' untuk membenarkan saya menjalankan tinjauan di 34 buah sekolah yang terlibat seperti dalam senarai yang dilampirkan.

4. Pertimbangan dan kerjasama pihak Yg. Berbahagia Dato' dalam perkara ini amat saya hargai dan didahului dengan ucapan ribuan terima kasih.

Sekian, terima kasih.

"BERKHIDMAT UNTUK NEGARA"

Yang menjalankan tugas,

Khairul Anuar Samsudin
Fakulti Teknologi Maklumat
Universiti Pendidikan Sultan Idris

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

## Appendix 4.0: Approval Letter from a State Educational Department

JABATAN PENDIDIKAN PERAK DARUL RIDZUAN,
JALAN TUN ABDUL RAZAK
Peti Surat 1PO11
PERAK DARUL RIDZUAN

Telefon 05-5274355
Faks 05-5277233

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

"PERAK GEMILANG"

J Pen Pk Pend S4757/Jld 20(086)
Tarikh 28 September 2004

En Khairul Anuar b. Samsudin
34, Taman Anson
Jalan Ketoyong
35900 Tanjong Malim
Perak

Tuan,

**KEBENARAN UNTUK MENJALANKAN KAJIAN**
**DI SEKOLAH-SEKOLAH MENENGAH / RENDAH NEGERI PERAK**

Saya diarahkan merujuk surat tuan bertarikh 22 September 2004 yang ada kaitannya dengan surat Kementerian Pendidikan Malaysia bilangan KP(BPPDP)603/5 Jld.8 (143) bertarikh 13 Ogos 2004 tentang perkara di atas.

2 Sukacita dimaklumkan bahawa pihak Jabatan Pendidikan Perak tiada halangan memberi kebenaran kepada tuan untuk menjalankan kajian dan soal selidik bertajuk **' Enhancing Students Spatial Ability Through Constructivist WEB-Based Virtual Environment To Facilitate Learning Of Engineering Drawing Fundamental'** di sekolah-sekolah dalam lampiran

3. Kehadiran tuan/puan membuat kajian di sekolah berkenaan tidak seharusnya menjejaskan proses pengajaran dan pembelajaran di sekolah berkenaan.

Sekian, terima kasih.

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"BERKHIDMAT UNTUK NEGARA"

Saya yang menurut perintah,

**( ADAM BIN DARUS )**
Unit Perhubungan dan Pendaftaran,
Sektor Pengurusan Sekolah,
b.p Pengarah Pelajaran Perak.

s.k 1. Pengarah Pelajaran Perak

AD / KAJISELIDIK / 2004

*CINTAILAH BAHASA KITA*

05-4506832 pustaka.upsi.edu.my Perpustakaan Tuanku Bainun Kampus Sultan Abdul Jalil Shah PustakaTBainun ptbupsi

**Appendix 5.0: A letter to an Engineering Drawing teacher for the survey research**

31hb Jan. 2005

Kepada;

Guru Subjek Lukisan Kejuruteraan
Sekolah Menengah Kebangsaan Besout
35600 Sungai, Perak Darul Ridzuan.

Melalui;

Pengetua
Sekolah Menengah Kebangsaan Besout
35600 Sungai, Perak Darul Ridzuan.

Tuan/Puan,

**Permohonan untuk menjalankan kajian mengenai pembelajaran subjek Lukisan Kejuruteraan melalui kaedah tinjauan.**

Dengan segala hormatnya adalah saya merujuk kepada perkara di atas untuk makluman tuan/puan.

2. Untuk makluman, saya perlu menjalankan tinjauan berkenaan di sekolah tuan/puan yang melibatkan para pelajar tingkatan 5 serta guru yang terlibat dengan matapelajaran Lukisan Kejuruteraan sebagai sebahagian daripada kajian kedoktoran yang telah pun mendapat kelulusan dari pihak Bahagian Perancangan dan Penyelidikan Dasar Pendidikan (Ruj:KP(BPPDP)603/5 Jld.8(143)) serta Jabatan Pendidikan Negeri Perak (Ruj: J.Pk.Pend.S4757/Jld.20(086)) seperti dalam lampiran.

3. Dapatan kajian akan digunakan dalam laporan atau tesis berkenaan sahaja dan tidak dihebahkan pada umum. Para pelajar juga hanya perlu menjawab soalan tinjauan di luar waktu kelas agar tidak menganggu proses pembelajaran mereka.

4. Saya amat berharap agar pihak tuan/puan sedia membantu saya dalam perkara ini dengan membenarkan saya atau wakil saya dengan memberikan kebenaran untuk tujuan tersebut.

5. Kerjasama dan pertimbangan pihak tuan/puan dalam perkara ini amat saya hargai dan saya dahului dengan ucapan ribuan terima kasih.

Sekian terima kasih. BERKHIDMAT UNTUK NEGARA

(Khairul Anuar Samsudin)
Fakulti Teknologi Maklumat & Komunikasi
Universiti Pendidikan Sultan Idris
35900 Tanjong Malim Perak

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**Appendix 6.0: A letter to the engineering drawing teacher for the experimental research**

15hb Jan. 2006

Kepada;
Guru Subjek Lukisan Kejuruteraan
Sekolah Menengah Kebangsaan Kuala Kubu Bahu
44000 Hulu Selangor
Selangor Darul Ehsan

Melalui;
Pengetua
Sekolah Menengah Kebangsaan Kuala Kubu Bahu
44000 Hulu Selangor
Selangor Darul Ehsan

Tuan

**Permohonan untuk menjalankan kajian experimental melibatkan pelajar-pelajar Lukisan Kejuruteraan.**

Dengan segala hormatnya adalah saya merujuk kepada perkara di atas untuk makluman tuan.

2. Untuk makluman, saya perlu menjalankan kajian experimental di sekolah tuan yang melibatkan para pelajar tingkatan 4 yang terlibat dengan matapelajaran Lukisan Kejuruteraan sebagai sebahagian daripada kajian kedoktoran yang telah pun mendapat kelulusan dari pihak Bahagian Perancangan dan Penyelidikan Dasar Pendidikan (Ruj:KP(BPPDP)603/5 Jld.8(143)) serta Jabatan Pendidikan Negeri Perak (Ruj: J.Pk.Pend.S4757/Jld.20(086)) seperti dalam lampiran.

3. Dapatan kajian akan digunakan dalam laporan atau tesis berkenaan sahaja dan tidak dihebahkan pada umum.

4. Saya amat berharap agar pihak tuan sedia membantu saya dalam perkara ini dengan membenarkan saya menjalankan experimen berkenaan selama 6 minggu di luar waktu kelas.

5. Kerjasama dan pertimbangan pihak tuan dalam perkara ini amat saya hargai dan saya dahului dengan ucapan ribuan terima kasih.

Sekian terima kasih. BERKHIDMAT UNTUK NEGARA

_____

(Khairul Anuar Samsudin)
Fakulti Teknologi Maklumat & Komunikasi
Universiti Pendidikan Sultan Idris
35900 Tanjong Malim Perak

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## Appendix 7.0: Consent Form for the Experimental Research

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### SURAT PERAKUAN DALAM KAJIAN EKSPERIMEN

Saya memahami bahawa penglibatan saya dalam kajian eksperimen ini adalah secara sukarela dan saya boleh menarik diri pada bila-bila masa tanpa ada sebarang implikasi negatif ke atas saya.

Saya memahami bahawa tujuan eksperimen ini adalah untuk mengkaji kesan latihan dalam keupayaan *Spatial Visualization* dan *Mental Rotation* setelah berlatih menggunakan *Spatial Trainer* selama 6 minggu di makmal sekolah.

Saya juga memahami bahawa mana-mana maklumat yang berkaitan dengan diri saya semasa kajian ini dijalankan adalah dilindungi dengan ketat dari pengetahuan umum dan ianya tidak akan menjadi sebarang rekod kekal atau mempengaruhi gred saya di dalam kelas. Saya memahami bahawa untuk kajian ini menjadi lebih bermakna dan berkesan, ianya memerlukan beberapa maklumat berkaitan diri saya. Saya amat memahami bahawa kerahsiaan yang tinggi akan sentiasa dijaga dan hanya penyelidik sahaja yang akan mempunyai akses kepada maklumat dan data peribadi yang berkaitan.

Dengan menandatangani di bawah ini, saya memberi pengakuan bahawa saya berumur 17 tahun, sihat secara fizikal dan mental, dan bersetuju dengan syarat-syarat yang dinyatakan di atas secara sukarela.

Tandatangan: _____ Tarikh: _____

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**Appendix 8.0: Stratified sampling to randomly assign students into three groups**

| Male participants | | Female participants | |
|---|---|---|---|
| 21 sets of 3 unique numbers per set. Range: From 1 to 3 | | 12 sets of 3 unique numbers per set Range: From 1 to 3 | |
| Set number: | Assigmnent: | Set number: | Assigmnent: |
| 1 | p1=3, p2=2, p3=1 | 1 | p1=1, p2=3, p3=2 |
| 2 | p4=2, p5=3, p6=1 | 2 | p4=3, p5=1, p6=2 |
| 3 | p7=2, p8=1, p9=3 | 3 | p7=2, p8=3, p9=1 |
| 4 | p10=1, p11=2, p12=3 | 4 | p10=2, p11=3, p12=1 |
| 5 | p13=1, p14=3, p15=2 | 5 | p13=1, p14=3, p15=2 |
| 6 | p16=2, p17=1, p18=3 | 6 | p16=1, p17=3, p18=2 |
| 7 | p19=1, p20=3, p21=2 | 7 | p19=1, p20=3, p21=2 |
| 8 | p22=2, p23=3, p24=1 | 8 | p22=3, p23=2, p24=1 |
| 9 | p25=1, p26=2, p27=3 | 9 | p25=3, p26=2, p27=1 |
| 10 | p28=3, p29=2, p30=1 | 10 | p28=3, p29=1, p30=2 |
| 11 | p31=1, p32=3, p33=2 | 11 | p31=1, p32=3, p33=2 |
| 12 | p34=1, p35=3, p36=2 | 12 | p34=3, p35=2, p36=1 |
| 13 | p37=1, p38=3, p39=2 | | |
| 14 | p40=1, p41=3, p42=2 | | |
| 15 | p43=2, p44=1, p45=3 | | |
| 16 | p46=3, p47=1, p48=2 | | |
| 17 | p49=1, p50=2, p51=3 | | |
| 18 | p52=2, p53=3, p54=1 | | |
| 19 | p55=3, p56=2, p57=1 | | |
| 20 | p58=2, p59=1, p60=3 | | |
| 21 | p61=1, p62=2 | | |

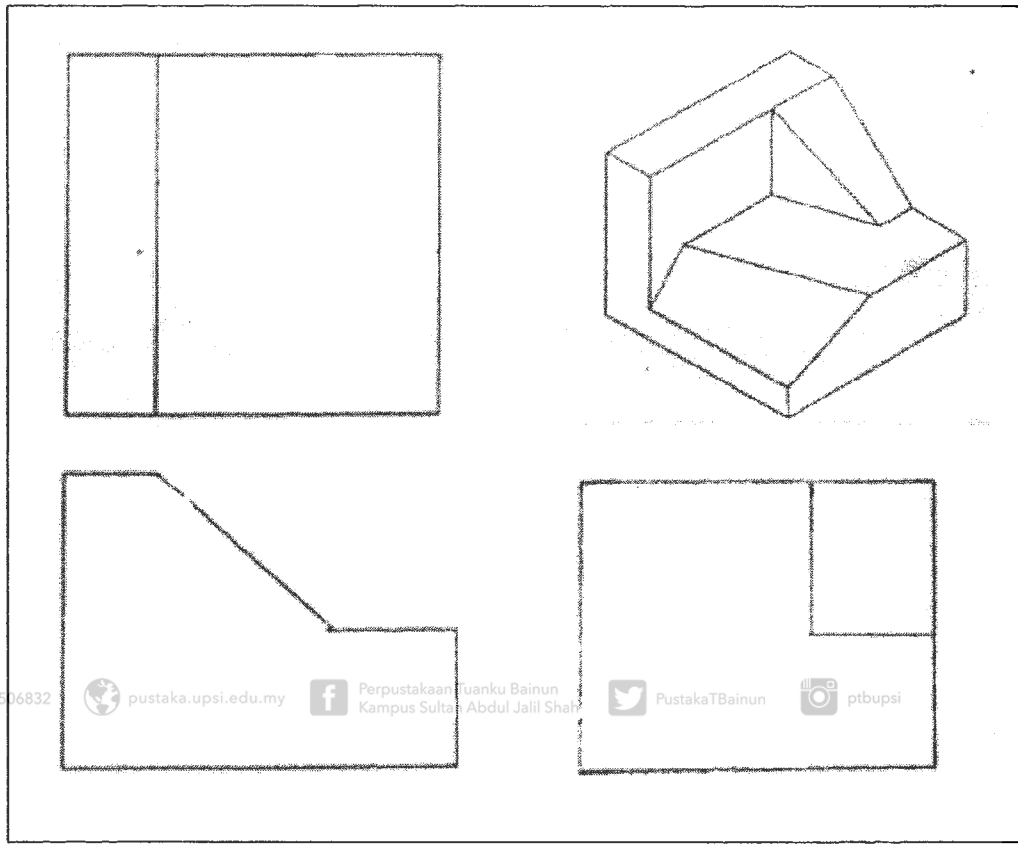
**Note: Letter 'p' refers to participant and numerals 1,2 and 3 for the set number refer to the three training conditions. Thus, p1= 3 refers to the first participant that is assigned to the third training condition.**

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## Appendix 9.0: Basic Engineering Drawing test

Arahan:
Lengkap pandangan-pandangan ortografik berdasarkan kepada lukisan isometric yang diberikan.

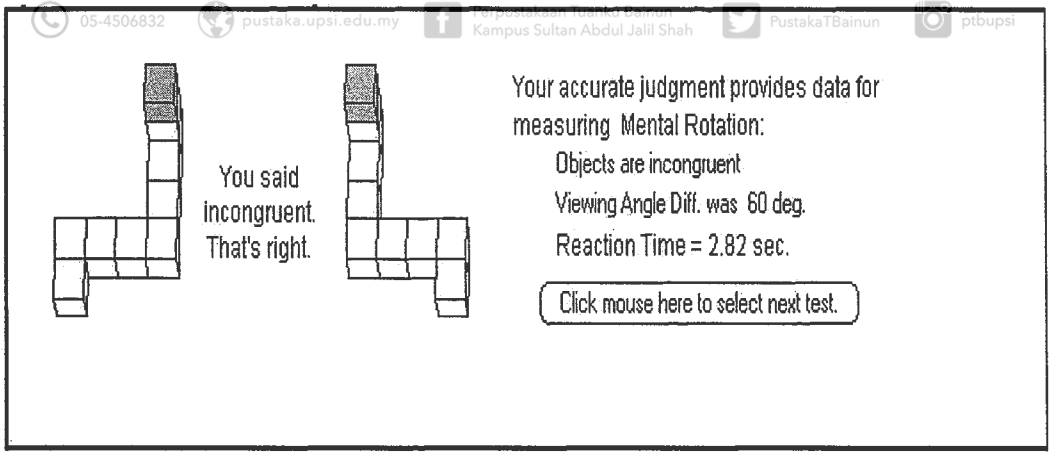
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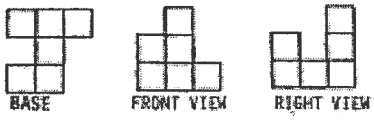
## Appendix 10.0: A sample of Mental Rotation test item

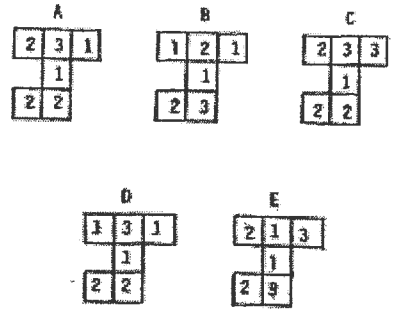



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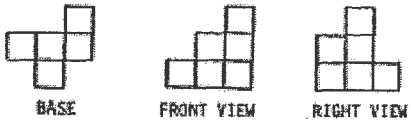
# Appendix 11.0: A few samples of Spatial Visualization test items

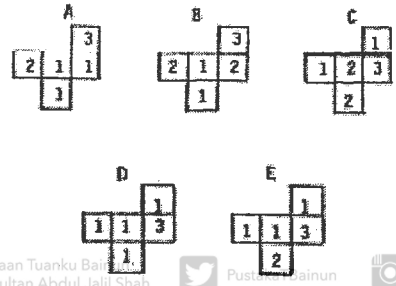
15. You are given the BASE, FRONT VIEW, and RIGHT VIEW of a building.
Find the mat plan for the building that uses the greatest number of cubes and also fits the given base and views.



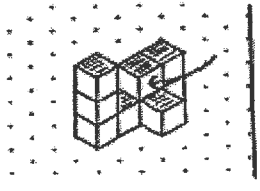




16. You are given the BASE, FRONT VIEW, and RIGHT VIEW of a building.
Find the mat plan for the building that uses the least number of cubes and also fits the given base and views.




17. How many cubes touch the indicated cube face to face?



A B C D E

1 2 3 4 5

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## Appendix 12.0: Spatial Training Attitudinal Questionnaire

(Tandakan ☑ pada kotak yang berkenaan.)
Dari pengalaman anda yang lepas setelah menggunakan kaedah latihan dalam aplikasi ini, berikan pendapat anda mengenai keberkesanan aplikasi ini mengikut skala yang diberikan.

| Item: | | *Sangat setuju* | *Setuju* | *Tidak pasti* | *Tidak setuju* | *Sangat tidak setuju* |
|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 |
| 1.0 | Penggunaan aplikasi membolehkan saya melihat masalah ruang dengan lebih jelas. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2.0 | Daya visualisasi saya bertambah baik dengan menjalankan aktiviti latihan melalui aplikasi ini. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3.0 | Interaksi/animasi dalam aplikasi ini membantu dalam penyelesaian masalah ruang kerana hubungan ` | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4.0 | Kemahiran saya meningkat kerana sentiasa dapat mengulang latihan untuk mana-mana bahagian yang keliru atau rumit | ☐ | ☐ | ☐ | ☐ | ☐ |
| 5.0 | Penggunaan aplikasi ini membolehkan saya menghasilkan lukisan pandangan 2D dari objek 3D dengan lebih baik. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 6.0 | Latihan melalui aplikasi ini membantu saya memahami konsep lukisan kejuruteraan lebih berkesan. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 7.0 | Latihan melalui aplikasi ini membantu saya mengingati kandungan latihan lebih berkesan. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 8.0 | Latihan melalui aplikasi ini membantu saya memberi tumpuan yang lebih. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 9.0 | Antaramuka dalam aplikasi ini mudah digunakan semasa dalam sesi latihan. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 10.0 | Susunan dalam siri latihan adalah teratur dan sistematik mengikut tahap kemahiran yang diperlukan. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 11.0 | Aplikasi ini bila digunakan adalah responsif dan bertindak dengan cepat. | ☐ | ☐ | ☐ | ☐ | ☐ |
| 12.0 | Objek-objek latihan adalah bersesuaian dan dapat membantu dalam meningkatkan kemahiran ruang saya. | ☐ | ☐ | ☐ | ☐ | ☐ |

Anda juga digalakkan menulis pengalaman anda mengenai sesi latihan kemahiran ruang di bawah;

.....

.....

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## Appendix 13.0: Consent Form for the Survey Research

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### SURAT PERAKUAN UNTUK KAJIAN TINJAUAN

Saya memahami bahawa penglibatan saya dalam kajian tinjauan ini adalah secara sukarela dan saya boleh menarik diri pada bila-bila masa tanpa ada sebarang implikasi negatif ke atas saya.

Saya memahami bahawa tujuan kajian ini adalah untuk mengkaji persepsi pelajar terhadap pembelajaran dalam matapelajaran Lukisan Kejuruteraan pada tahun pertama semasa di tingkatan empat.

Saya juga memahami bahawa mana-mana maklumat yang berkaitan dengan diri saya semasa kajian ini dijalankan adalah dilindungi dengan ketat dari pengetahuan umum dan ianya tidak akan menjadi sebarang rekod kekal atau mempengaruhi gred saya di dalam kelas. Saya memahami bahawa untuk kajian ini menjadi lebih bermakna dan berkesan, ianya memerlukan beberapa maklumat berkaitan diri saya. Saya amat memahami bahawa kerahsiaan yang tinggi akan sentiasa dijaga dan hanya penyelidik sahaja yang akan mempunyai akses kepada maklumat dan data peribadi yang berkaitan.

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Dengan menandatangani di bawah ini, saya memberi pengakuan bahawa saya berumur 17 tahun, sihat secara fizikal dan mental, dan bersetuju dengan syarat-syarat yang dinyatakan di atas secara sukarela.

Tandatangan: _____ Tarikh: _____

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## Appendix 14.0: Students Perception Questionnaire (SPQ)

Borang tinjauan mengenai tahap persepsi pelajar terhadap kebolehan belajar dalam Subjek Lukisan Kejuruteraan.

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**Bahagian A:Tandakan [ ✓ ] dalam kotak yang sesuai.**

1.0 Jantina: Lelaki ☐ Perempuan ☐

2.0 Bangsa: Melayu ☐ Cina ☐ India ☐ Lain-lain ☐

3.0 Pencapaian Matematik: Gred A ☐ Gred B ☐ Gred C ☐ Gred D ☐ pada peringkat PMR:

**Bahagian B:**

Diberikan ada senarai topik atau unit dalam kursus Lukisan Kejuruteraan yang telah anda pelajari. Tandakan [ ✓ ] dalam kotak yang sesuai bagi mewakili pendapat anda tentang tahap kebolehan anda mengikuti pembelajaran bagi setiap topik berkenaan mengikut skala berikutnya:

| |
|---|
| **1 = Sangat Sukar (SS)** |
| **2 = Sukar (S)** |
| **3 = Tidak Pasti (TP)** |
| **4 = Mudah (M)** |
| **5 = Sangat Mudah (SM)** |

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**Continued... Appendix 14.0**

| | | Sangat Sukar (Extremely difficult) | | | | Sangat Muda (Extremely E |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| 1. | Pengenalan kepada Lukisan Kejuruteraan. (*Introduction to Engineering Drawing*) | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2. | Lakaran (*Sketching*) | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3. | Garisan dan Pengurufan (*Lines and Lettering*) | ☐ | ☐ | ☐ | ☐ | ☐ |
| 4. | Geometri (*Geometry*) | ☐ | ☐ | ☐ | ☐ | ☐ |
| 5. | Lukisan Terbantu Komputer (I) (*Computer Aided I*) | ☐ | ☐ | ☐ | ☐ | ☐ |
| 6. | Lukisan Orthografik (*Orthographic Drawings*) | ☐ | ☐ | ☐ | ☐ | ☐ |
| 7. | Pandangan Bantuan (*Auxiliary Drawings*) | ☐ | ☐ | ☐ | ☐ | ☐ |
| 8. | Lukisan Isometrik (*Isometric Drawings*) | ☐ | ☐ | ☐ | ☐ | ☐ |
| 9. | Lukisan Oblik (*Oblique Drawings*) | ☐ | ☐ | ☐ | ☐ | ☐ |

*[ TERIMA KASIH ]*

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## Appendix 15.0: Spatial Experience Questionnaire

***Soalselidik Pengalaman Spatial (Spatial Experience Questionnare)***

Diberikan adalah senarai aktiviti-aktiviti yang mungkin anda pernah terlibat. Dari pengalaman yang lepas dan semasa berikan pendapat anda mengenai tahap keterlibatan anda mengikuti skala yang diberikan.

(Tandakan ☑ pada kotak yang berkenaan.)

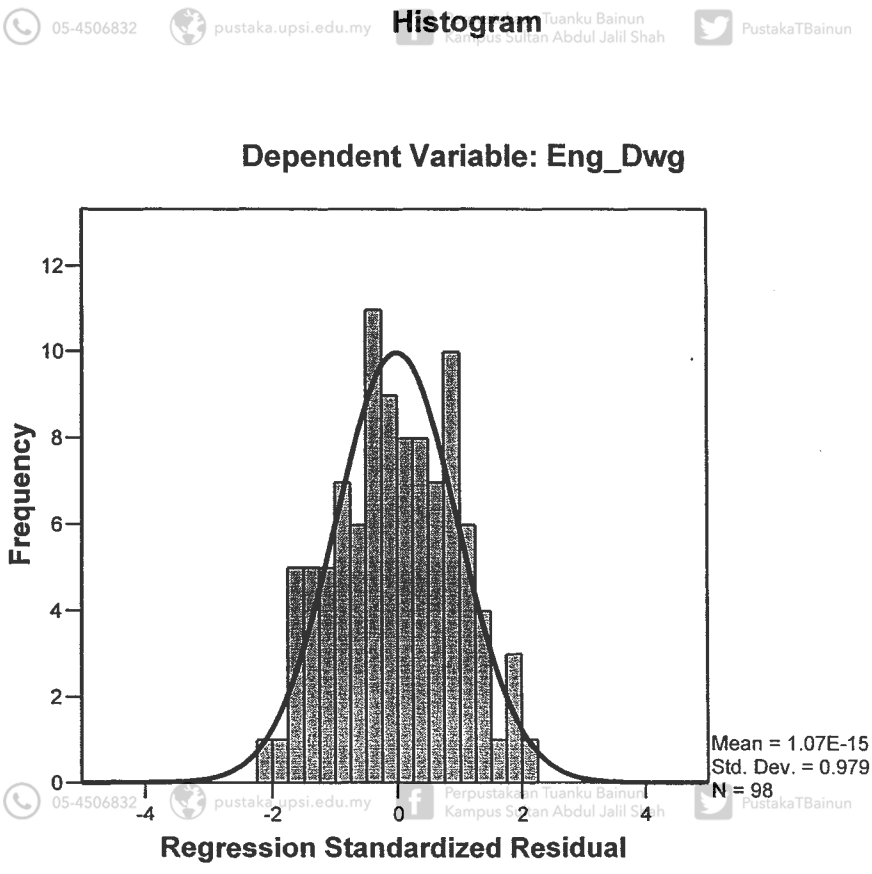
| | | | |
|---|---|---|---|
| 1.0 | Jantina | ☐ Perempuan | ☐ Lelaki |
| 2.0 | Tingkatan | ☐ 4 | ☐ 5 |
| 3.0 | Ras | ☐ Melayu ☐ Cina ☐ India | ☐ Lain-lain |

| **Item:** | **Sangat kerap** *(Always)* **4** | **Kerap** **3** | **Jarang** **2** |
|---|---|---|---|
| 1. Bermain dengan catur (chess) | ☐ | ☐ | ☐ |
| 2. Bermain puzzle/jigsaw/maze dengan rakan-rakan | ☐ | ☐ | ☐ |
| 3. Bermain dengan permainan tangram | ☐ | ☐ | ☐ |
| 4. Bermain jengket-jengket (*hopskotch*) | ☐ | ☐ | ☐ |
| 5. Mereka dan membina objek daripada kertas ic. origami | ☐ | ☐ | ☐ |
| 6. Membina model daripada blok binaan LEGO dan sebagainya | ☐ | ☐ | ☐ |
| 7. Membuat model-model daripada straw/kayu balsa/plastik | ☐ | ☐ | ☐ |
| 8. Menceraikankan dan memasang komponen-koniponen | ☐ | ☐ | ☐ |
| 9. Memasang bahagian/bahan kepingan untuk menjadi model | ☐ | ☐ | ☐ |
| 10. Memperbaiki alat-alat yang rosak | ☐ | ☐ | ☐ |
| 11. Melukis rajah, gambar, bentuk dan objek | ☐ | ☐ | ☐ |
| 12. Membuat lakaran bebas | ☐ | ☐ | ☐ |
| 13. Menggunakan atau membaca peta | ☐ | ☐ | ☐ |
| 14. Trekking dalam hutan atau taman | ☐ | ☐ | ☐ |
| 15. Menggembara dalam persekitaran bangunan yang besar dan mencabar | ☐ | ☐ | ☐ |
| 16. Menggunakan permainan komputer i.e 3D games | ☐ | ☐ | ☐ |
| 17. Menggunakan perisian animasi/simulasi | ☐ | ☐ | ☐ |
| 18. Menggunakan perisian rekabentuk berbantu komputer, CAD | ☐ | ☐ | ☐ |
| 19. Menggunakan perisian mengecat e.g. Microsoft Paint | ☐ | ☐ | ☐ |
| 20. Bermain dengan permainan baling | ☐ | ☐ | ☐ |
| 21. Terlibat dengan sukan melibatkan aktiviti memanjat | ☐ | ☐ | ☐ |
| 22. Bermain sukan seperti bolasepak/hoki/netball | ☐ | ☐ | ☐ |
| 23. Terlibat dengan sukan seperli badminton/tenis/squasi | ☐ | ☐ | ☐ |
| 24. Memain alatan muzik ketukan seperti gendang/piano dll. | ☐ | ☐ | ☐ |
| 25. Memain alatan muzik petikan seperti gitar/biola dll. | ☐ | ☐ | ☐ |

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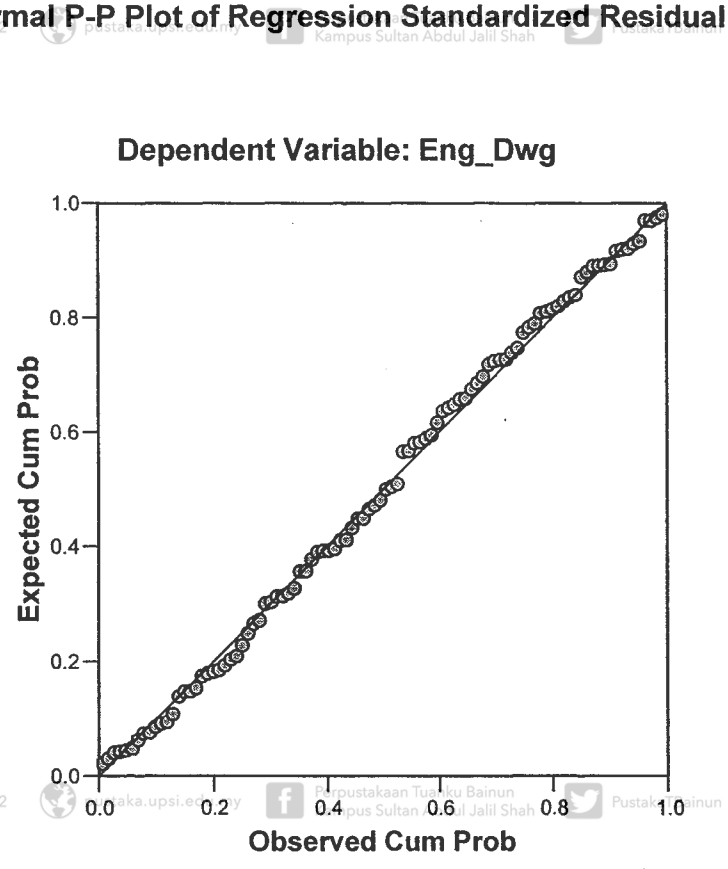
## Appendix 16.0: Histogram of the residuals with a normal curve

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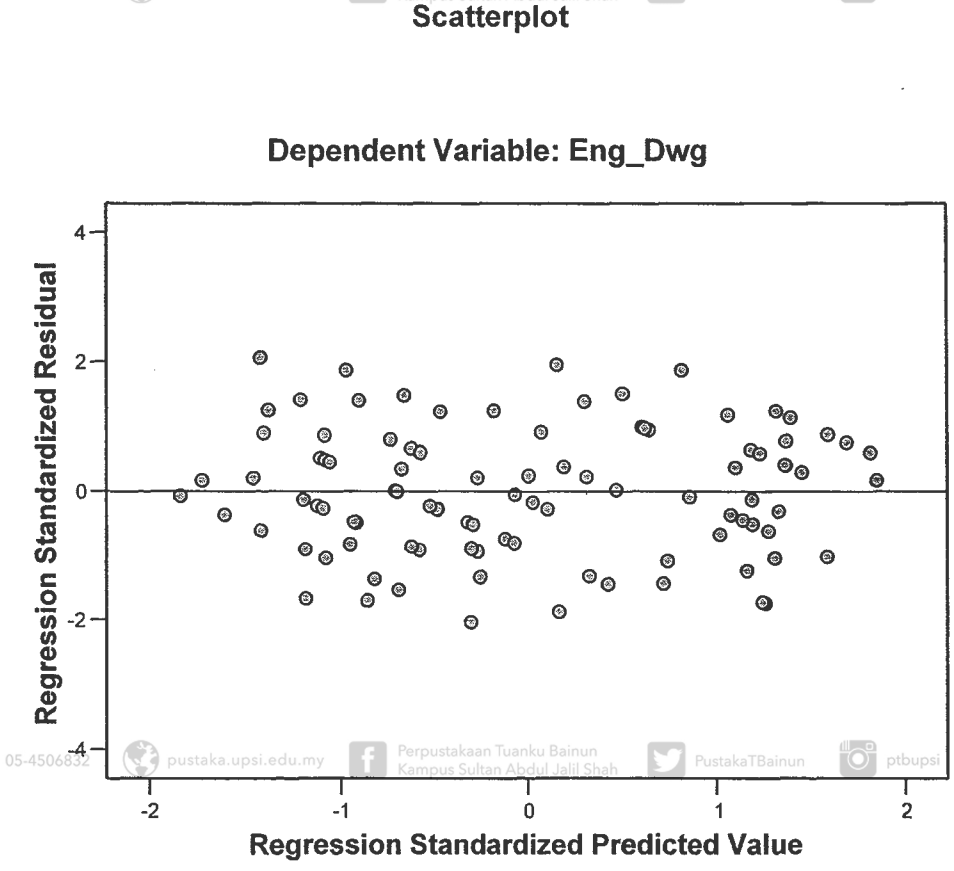
## Appendix 17.0: Normal P-P Plot of Regression Standardized Residual




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## Appendix 18.0: Regression Standardized Residuals against Regression Standardized Predicted Value

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## Appendix 19.0: Variance Inflation Factors (VIF) for the multicollinearity testing

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**Coefficients[a]**

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. | 95% Confidence Interval for B | | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | | Lower Bound | Upper Bound | Tolerance | VIF |
| 1 | (Constant) | 4.735 | 1.631 | | 2.903 | .005 | 1.496 | 7.975 | | |
| | Post_Spatial Visualization | .262 | .027 | .681 | 9.544 | .000 | .208 | .317 | .779 | 1.284 |
| | Post_Mental Rotation Accuracy | -.007 | .059 | -.008 | -.123 | .902 | -.125 | .111 | .879 | 1.138 |
| | Post_Mental Rotation Speed | -.003 | .006 | -.038 | -.550 | .584 | -.015 | .009 | .823 | 1.215 |
| | Gender | 1.334 | .282 | .306 | 4.734 | .000 | .775 | 1.894 | .947 | 1.055 |

a. Dependent Variable: Eng_Dwg

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